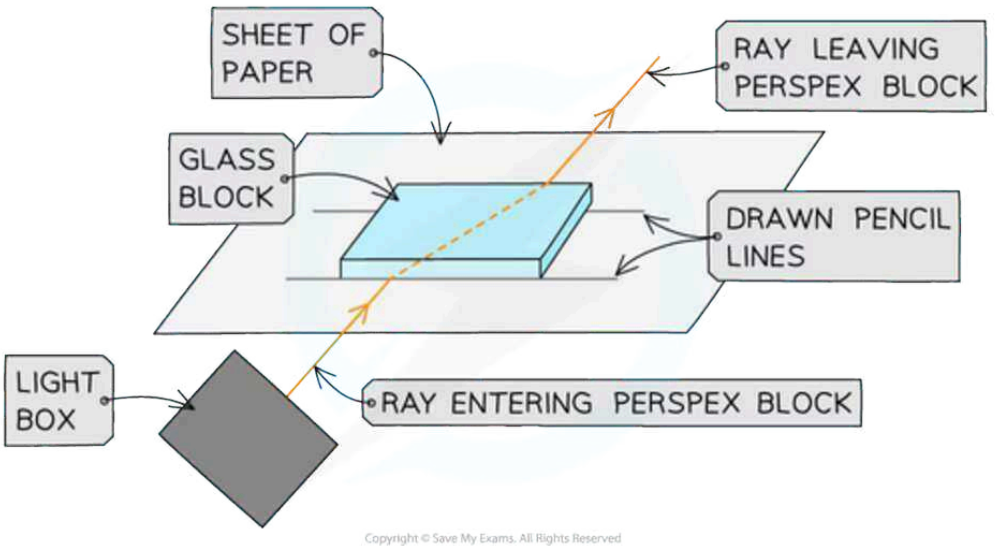
Your notes



Apparatus to investigate refraction

1. Place the glass block on a sheet of paper, and carefully draw around the rectangular perspex block using a pencil
2. Switch on the ray box and direct a beam of light at the side face of the block
3. Mark on the paper:
 - A point on the ray close to the ray box
 - The point where the ray enters the block
 - The point where the ray exits the block
 - A point on the exit light ray which is a distance of about 5 cm away from the block
4. Draw a dashed line normal (at right angles) to the outline of the block where the points are
5. Remove the block and join the points marked with three straight lines
6. Replace the block within its outline and repeat the above process for a ray striking the block at a different angle
7. Repeat the procedure for each shape of perspex block (prism and semi-circular)

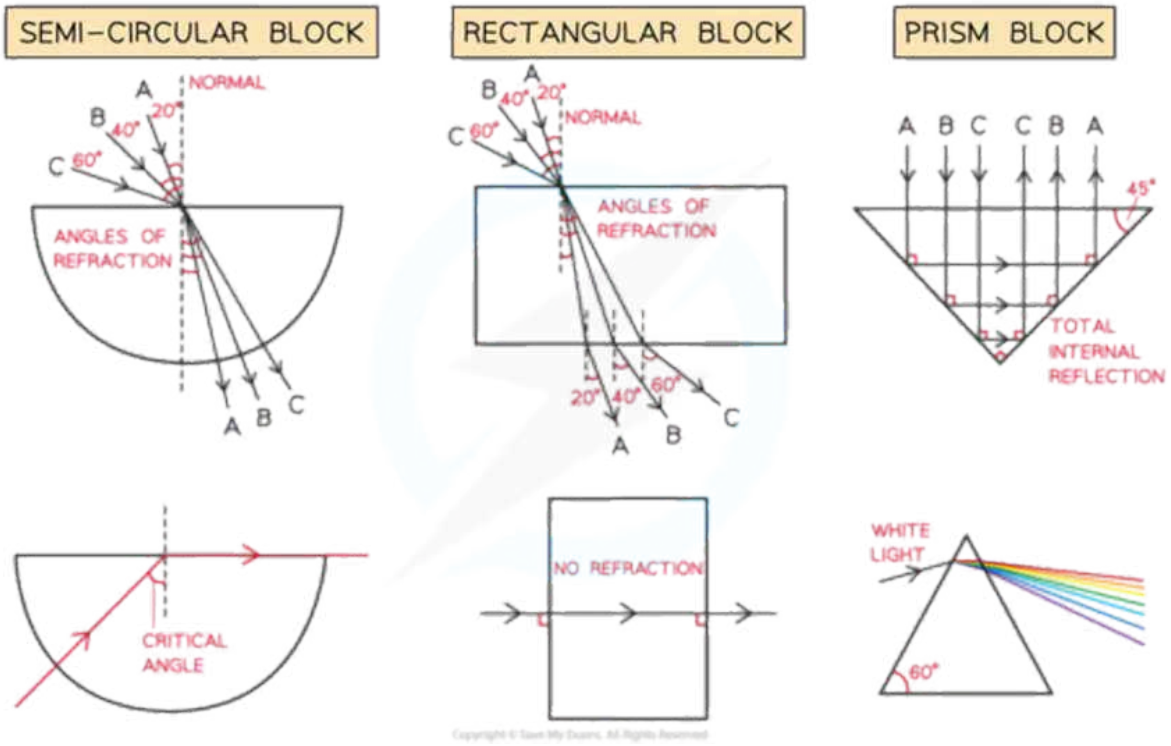
Analysis of Results

- Consider the light paths through the different-shaped blocks

Rays Passing through the Blocks

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Your notes



Refraction of light through different shapes of perspex blocks

- The final diagram for each shape will include multiple light ray paths for the different angles of incidences (*i*) at which the light strikes the blocks
- This will help demonstrate how the angle of refraction (*r*) changes with the angle of incidence
 - Label these paths clearly with (1) (2) (3) or **A**, **B**, **C** to make these clearer
- Angles *i* and *r* are always measured from the **normal**
- For light rays entering the perspex block, the light ray refracts **towards** the central line:

i > r

- For light rays exiting the perspex block, the light ray refracts **away** from the central line:

i < r

- When the angle of incidence is 90° to the perspex block, the light ray does **not** refract, it passes straight through the block:

i = r

Evaluating the Experiment

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Systematic Errors:

- An error could occur if the 90° lines are drawn incorrectly
 - Use a set square to draw perpendicular lines

Random Errors:

- The points for the incoming and reflected beam may be inaccurately marked
 - Use a sharpened pencil and mark in the middle of the beam
- The protractor resolution may make it difficult to read the angles accurately
 - Use a protractor with a higher resolution

Safety Considerations

- The ray box light could cause burns if touched
 - Run burns under cold running water for at least five minute
- Looking directly into the light may damage the eyes
 - Avoid looking directly at the light
 - Stand behind the ray box during the experiment
- Keep all liquids away from the electrical equipment and paper

Exam Tip

In your examination, you might be asked to write a method explaining how you might investigate the refraction of light through different shaped blocks

As part of this method you should describe:

- What equipment you need
- How you will use the equipment
- How you will trace the rays of light before, while and after they pass through the block

Your notes

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Snell's Law

Your notes

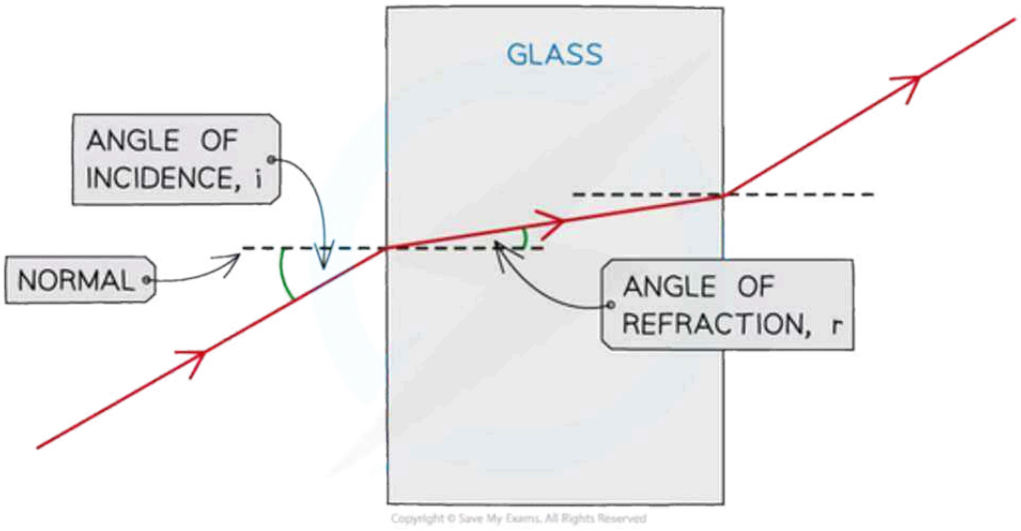
Refractive Index & Snell's Law

Refractive Index

- The refractive index is a number which is related to the speed of light in the material (which is **always less** than the speed of light in a vacuum):
- The refractive index is a number that is **always larger than 1** and is different for different materials
 - Objects which are more **optically dense** have a **higher** refractive index, eg. *n* is about 2.4 for diamond
 - Objects which are less **optically dense** have a **lower** refractive index, eg. *n* is about 1.5 for glass
- Since refractive index is a **ratio**, it has **no units**

Snell's Law

- When light enters a **denser** medium (such as glass) it slows down and bends **towards** the normal
 - How much the light bends depends on the **density** of the material



Angle of incidence i and angle of refraction r through a glass block

- If light travels from a **less** dense to a **more** dense medium (e.g. air to glass), ***r* < i** (bends towards the normal)
- If light travels from a **more** dense to a **less** dense medium (e.g. glass to air), ***r* > i** (bends away from the normal)

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- The angles of incidence and refraction are related by an equation known as **Snell's Law:**

$$n = \frac{\sin i}{\sin r}$$

- Where:
 - n = the refractive index of the material
 - i = angle of incidence of the light (°)
 - r = angle of refraction of the light (°)
- 'Sin' is the trigonometric function 'sine' which is on a scientific calculator

Your notes

Worked example

A ray of light enters a glass block of refractive index 1.53 making an angle of 15° with the normal before entering the block.

Calculate the angle it makes with the normal after it enters the glass block.

Answer:

Step 1: List the known quantities

- Refractive index of glass, n = 1.53
- Angle of incidence, i = 15°

Step 2: Write the equation for Snell's Law

$$n = \frac{\sin i}{\sin r}$$

Step 3: Rearrange the equation and calculate sin (r)

$$\sin r = \frac{\sin i}{n}$$

$$\sin r = \frac{\sin(15°)}{1.53} = 0.1692$$

Step 4: Find the angle of refraction (r) by using the inverse sin function

$r = \sin^{-1}(0.1692) = 9.7 = 10°$

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Exam Tip

Important: (sin *i* / sin *r*) is not the same as (*i* / *r*). Incorrectly cancelling the sin terms is a very common mistake!

When calculating the value of *i* or *r* start by calculating the value of sin *i* or sin *r*.

You can then use the **inverse sin** function ($\sin^{-1}$ on most calculators by pressing 'shift' then 'sine') to find the angle.

One way to remember which way around *i* and *r* are in the fraction is remembering that 'i' comes before 'r' in the alphabet, and therefore is on the top of the fraction (whilst *r* is on the bottom).

Additionally, make sure your calculator is in **degrees** mode, not radians mode, when you are given *i* and *r* in degrees.


Your notes

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Total Internal Reflection

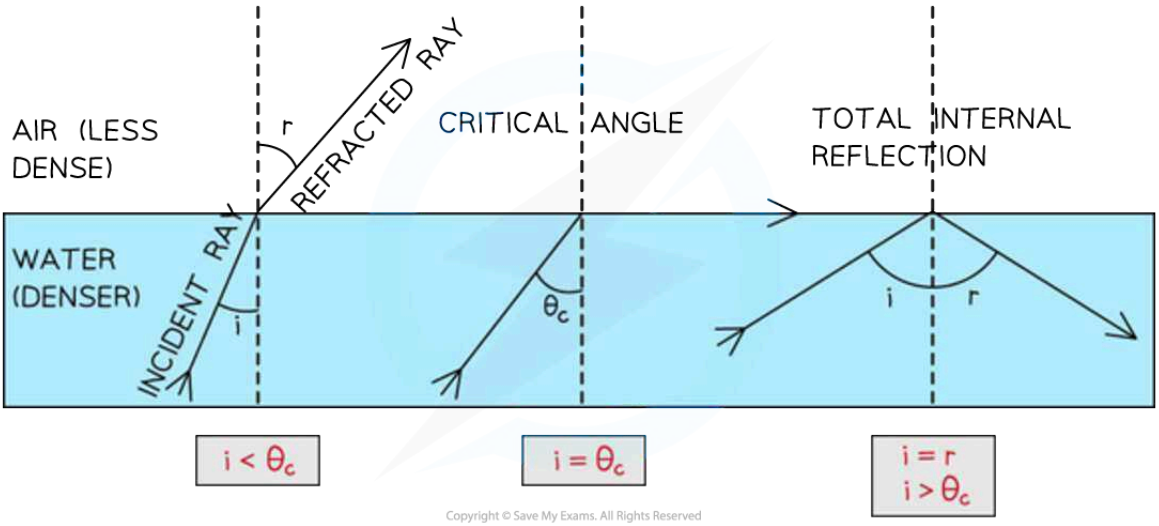
Your notes

Total Internal Reflection

- Sometimes, when light is moving from a **denser** medium towards a **less dense** one, instead of being refracted, all of the light is **reflected**
 - This phenomenon is called **total internal reflection**
- Total internal reflection (TIR) occurs when:

 The angle of incidence is greater than the critical angle and the incident material is denser than the second material
- Therefore, the **two** conditions for total internal reflection are:
 - The angle of incidence > the critical angle
 - The incident material is denser than the second material

Critical Angle and TIR



TIR occurs when the angle of incidence is greater than the angle of reflection

- Total internal reflection is utilised in:
 - Optical fibres e.g. endoscopes
 - Prisms e.g. periscopes

Prisms

- Prisms are used in a variety of optical instruments, including:

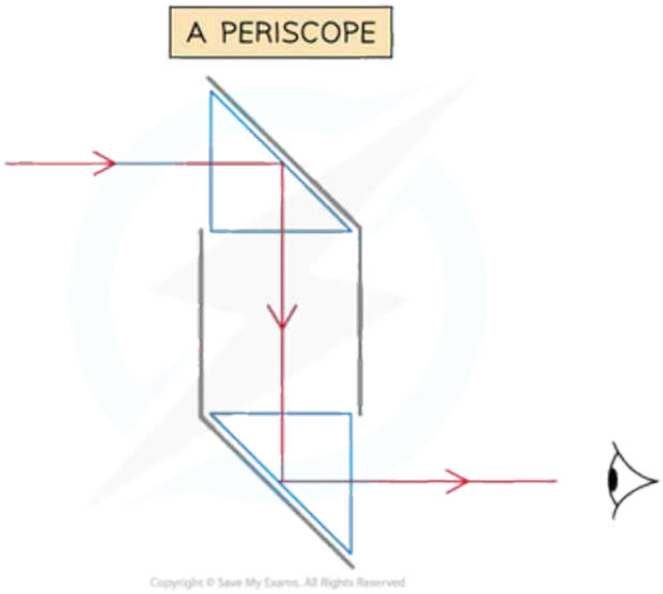
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Your notes

- Periscopes
- Binoculars
- Telescopes
- Cameras

- They are also used in safety reflectors for bicycles and cars, as well as posts marking the side or edge of roads

- A periscope is a device that can be used to see over tall objects
 - It consists of two right-angled prisms



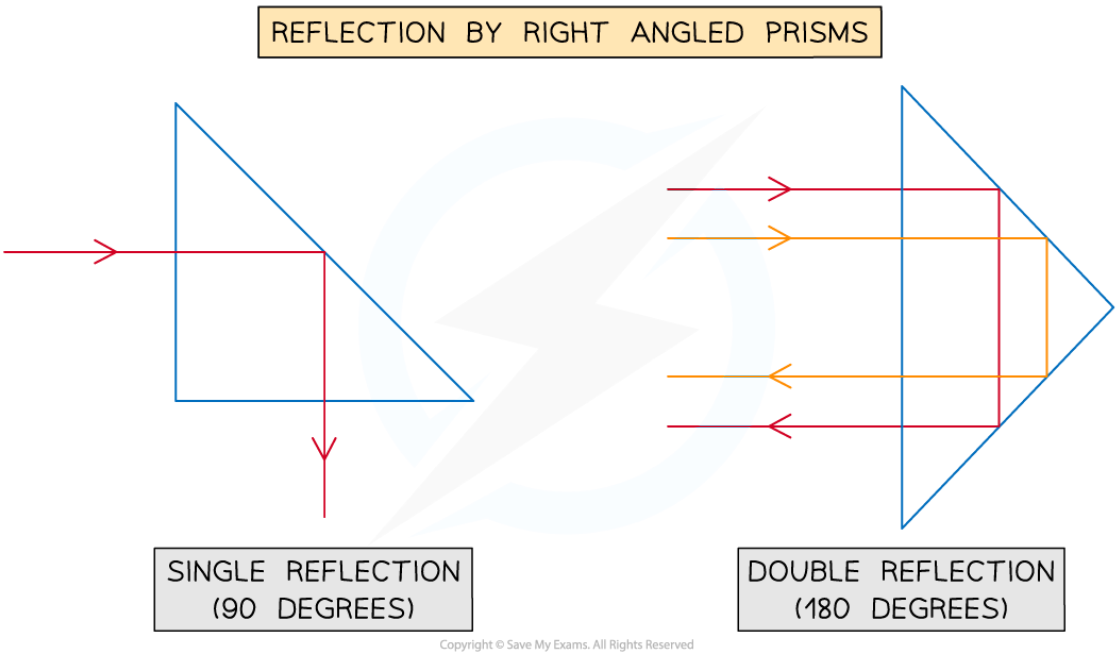
Reflection of light through a periscope

- The light totally internally reflects in both prisms

Internal Reflection in Prisms

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Your notes



Single and double reflection through right-angled prisms

Exam Tip

If asked to name the phenomena make sure you give the whole name – **total internal reflection**

Remember: total internal reflection occurs when light travels from a denser material to less dense material and **ALL** of the light is reflected.

If asked to give an example of a use of total internal reflection, first state the name of the object that causes the reflection (e.g. a right-angled prism) and then name the device in which it is used (e.g. a periscope)

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Refractive Index & Critical Angle Equation


Your notes

- The critical angle, *c*, of a material is related to its refractive index, *n*
- The relationship between the two quantities is given by the equation:

$$\sin c = \frac{1}{n}$$

- This can also be rearranged to calculate the refractive index, *n*:

$$n = \frac{1}{\sin c}$$

- This equation shows that:
 - The larger the **refractive index** of a material, the smaller the **critical angle**
 - Light rays inside a material with a **high refractive index** are more likely to be **totally internally reflected**

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Your notes

Worked example

Opals and diamonds are transparent stones used in jewellery. Jewellers shape the stones so that light is reflected inside.Compare the critical angles of opal and diamond and explain which stone would appear to sparkle more.

The refractive index of opal is about 1.5

The refractive index of diamond is about 2.4

Step 1: List the known quantities

- Refractive index of opal, $n_o = 1.5$
- Refractive index of diamond, $n_d = 2.4$

Step 2: Write out the equation relating critical angle and refractive index

$$\sin c = \frac{1}{n}$$

Step 3: Calculate the critical angle of opal (c_o)

$$\sin(c_o) = 1 \div 1.5 = 0.6667$$

$$c_o = \sin^{-1}(0.6667) = 41.8 = 42°$$

Step 4: Calculate the critical angle of diamond (c_d)

$$\sin(c_d) = 1 \div 2.4 = 0.4167$$

$$c_d = \sin^{-1}(0.4167) = 24.6 = 25°$$

Step 5: Compare the two values and write a conclusion

- Total internal reflection occurs when the angle of incidence of light is **larger** than the critical angle ($i > c$)
- In opal, total internal reflection will occur for angles of incidence between 42° and 90°
- The critical angle of diamond is **lower** than the critical angle of opal ($c_o > c_d$)
- This means light rays will be totally internally reflected in diamond over a **larger** range of angles (25° to 90°)
- Therefore, more total internal reflection will occur in diamond hence it will appear to sparkle more than the opal

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Exam Tip

When calculating the value of the critical angle using the above equation:

- First use the refractive index, *n*, to find sin(*c*)
- Then use the **inverse** sin function ($\sin^{-1}$) to find the value of *c*

Your notes

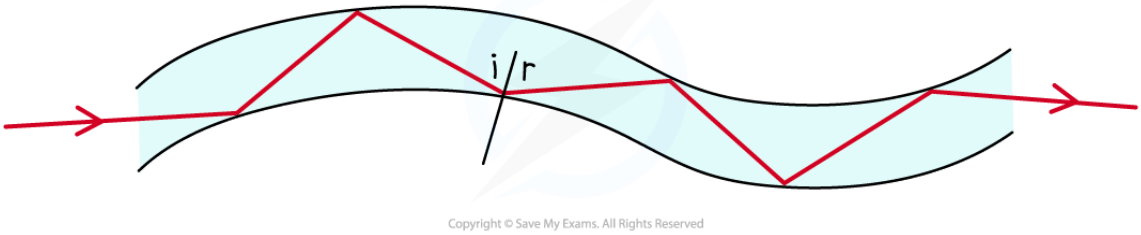
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Optical Fibres

Your notes

- Total internal reflection is used to reflect light along optical fibres, meaning they can be used for
 - Communications
 - Endoscopes
 - Decorative lamps
- Light travelling down an optical fibre is totally internally reflected each time it hits the edge of the fibre
- This means information can be transmitted over long distances with minimal loss

Total Internal Reflection in an Optical Fibre



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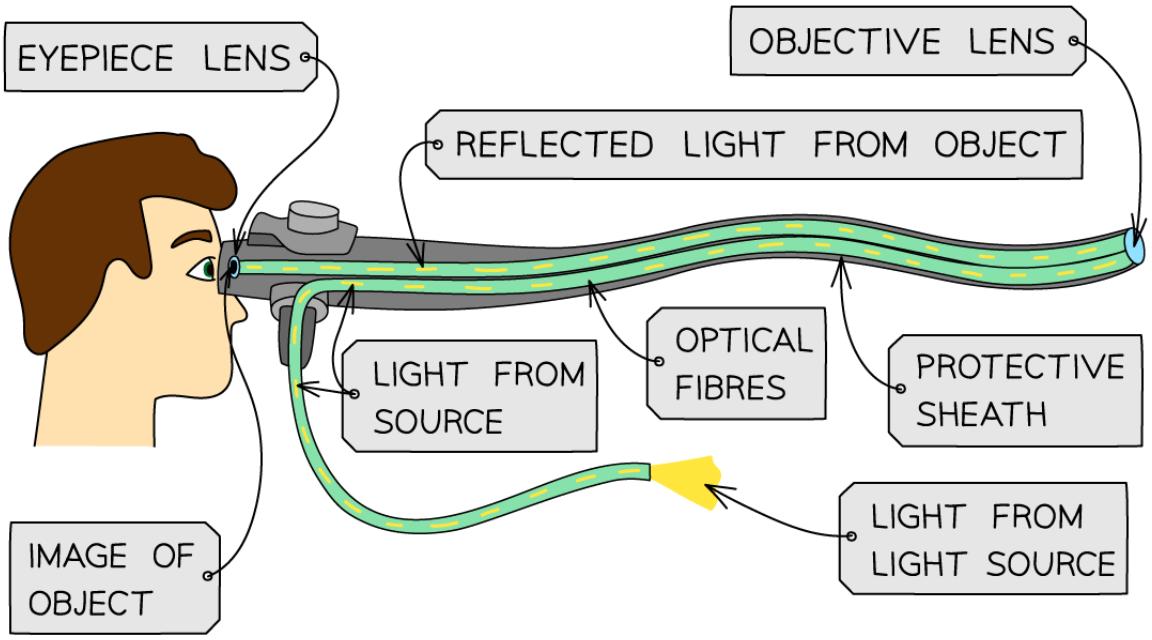
Optical fibres utilise total internal reflection for communications

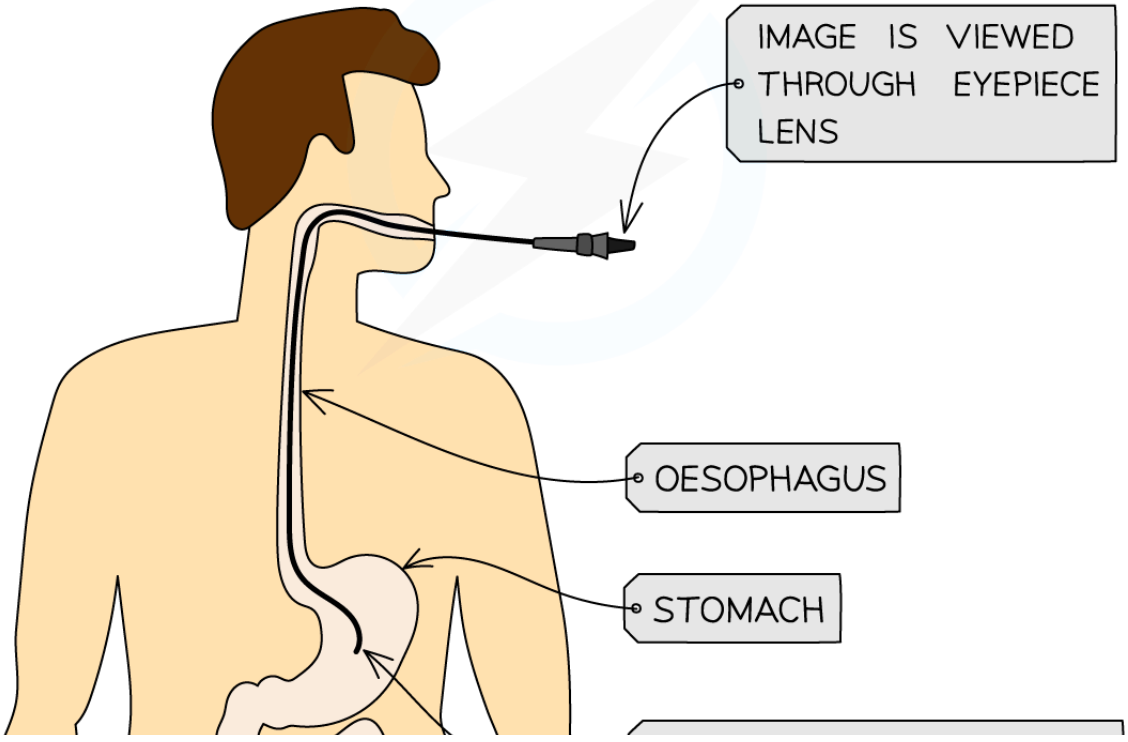
- Optical fibres are also used in medicine in order to see within the human body

Optical Fibres in Medicine

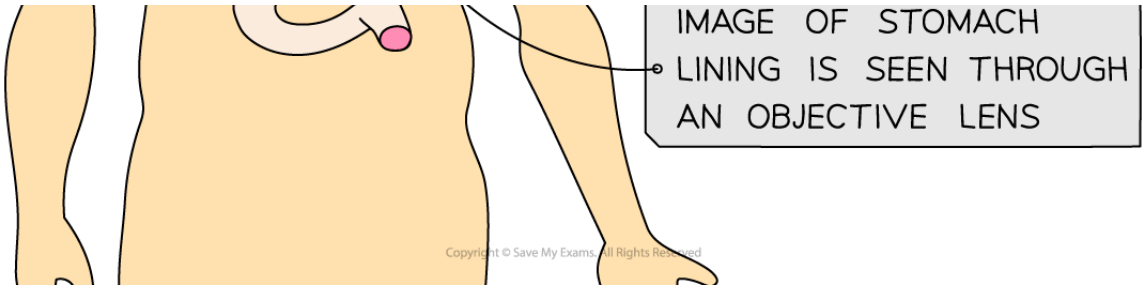
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Your notes





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Endoscopes utilise total internal reflection to see inside a patient's body

Your notes

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Thin Lenses

Your notes

Features of Lens Diagrams

- Lens diagrams can be described using the following terms:
 - Principal axis
 - Principal focus, or focal point
 - Focal length
- The principal axis is defined as:

 A line which passes through the centre of a lens

- The principal focus, or focal point, is defined as:

 The point at which rays of light travelling parallel to the principal axis intersect the principal axis and converge or the point at which diverging rays appear to proceed

- Focal length is defined as:

 The distance between the centre of the lens and the principal focus

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Converging & Diverging Lenses

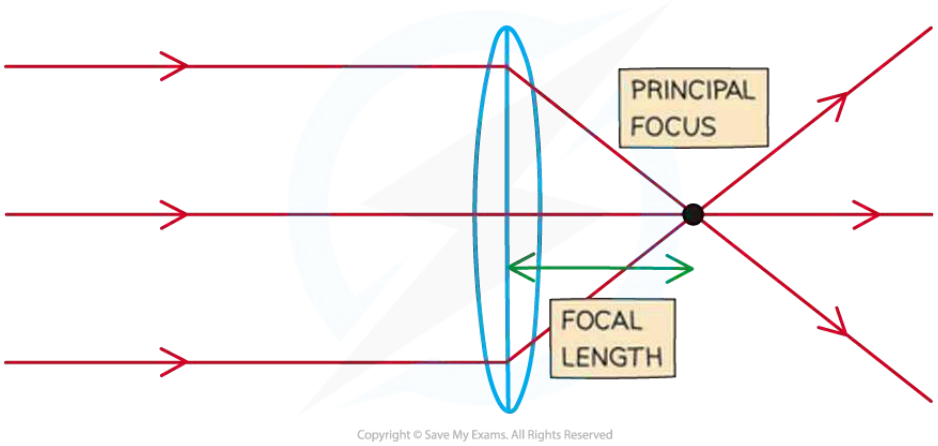
Your notes

- A lens is a piece of equipment that forms an image by **refracting** light
- There are two types of lens:
 - Converging
 - Diverging

Converging Lenses

- In a converging lens, parallel rays of light are brought to a focus
 - This point is called the **principal focus**
- This lens is sometimes referred to as a **convex** lens
- The distance from the lens to the principal focus is called the **focal length**
 - This depends on how **curved** the lens is
 - The **more** curved the lens, the **shorter** the focal length

Converging Lens



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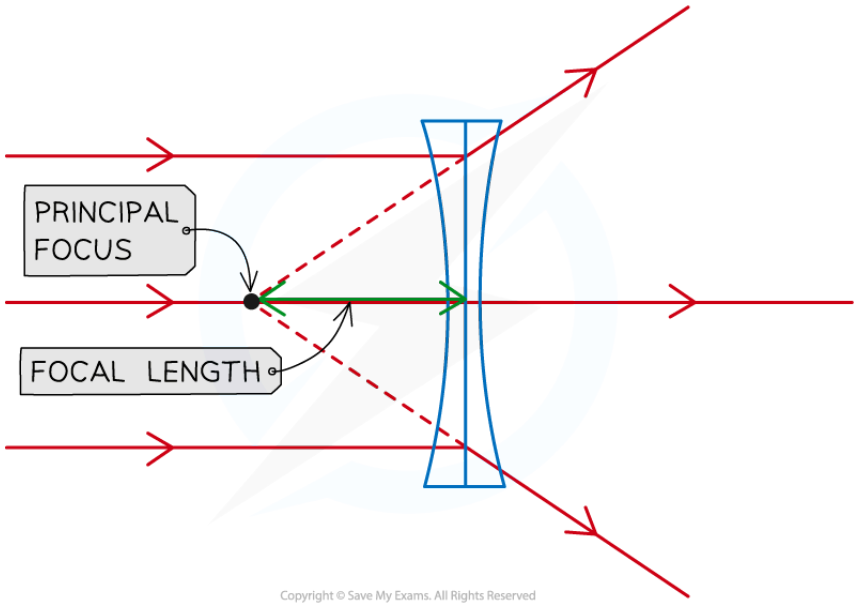
The focal length is the distance from the lens to the principal focus. In a converging lens, parallel light rays converge on the principal focus.

Diverging Lenses

- In a diverging lens, parallel rays of light are made to diverge (spread out) from a point
 - This lens is sometimes referred to as a **concave** lens
- The principal focus is now the point from which the rays appear to diverge from

Diverging Lens

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Parallel rays from a diverging lens appear to diverge from the principal focus

Representing Lenses

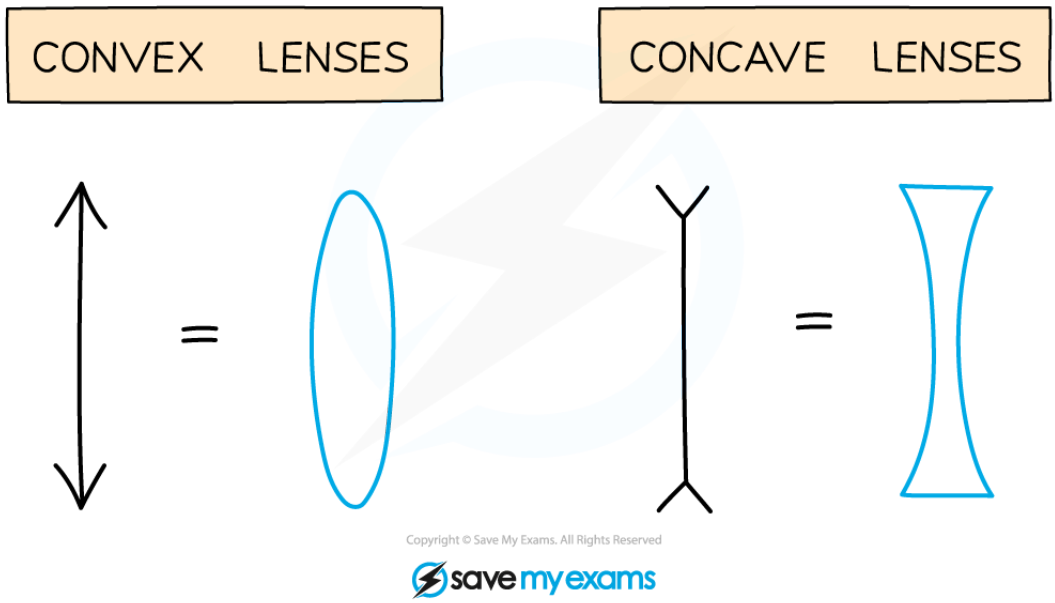
- In diagrams, the following symbols are often used to represent each type of lens:

Symbols for Lenses

Your notes

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Your notes



Concave and convex symbols

Exam Tip

Make sure you remember the symbol for each type of lens, as you will be expected to draw these for ray diagrams in your exam!

To remember which lens is converging or diverging, think of the following: Con**v**ex lens = Con**v**erging

If you struggle with the difference between convex and concave, remember that a con**cave** shape curves inwards, like a **cave**.

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Real & Virtual Images

Your notes

Real & Virtual Images

- Images produced by lenses can be one of two types:
 - A real image
 - A virtual image

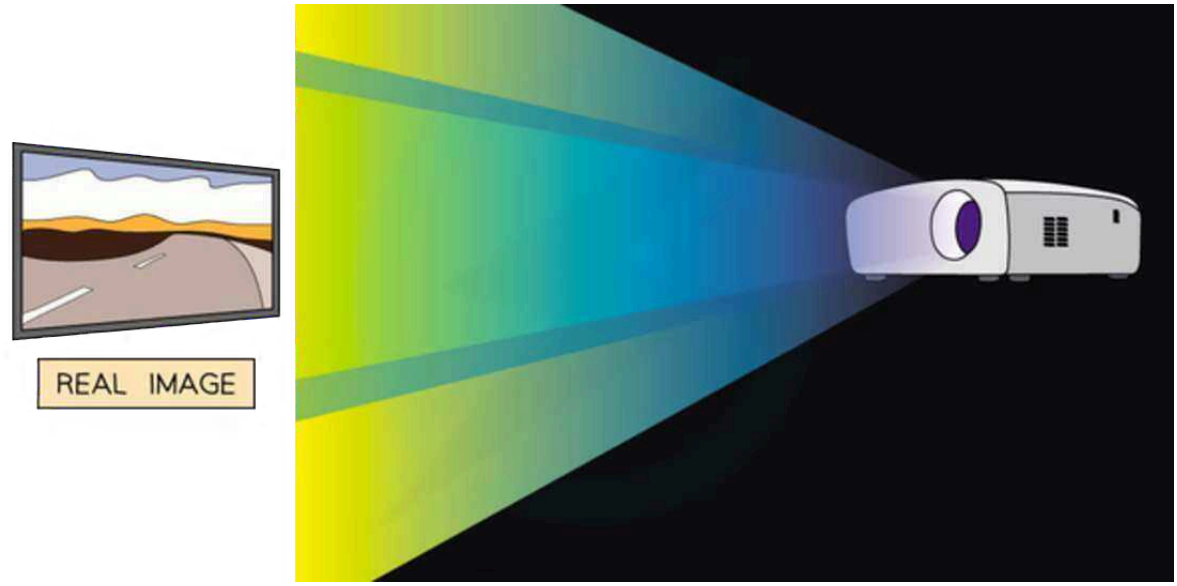
Real Images

- A real image is defined as:

 An image that is formed when the light rays from an object converge and meet each other and can be projected onto a screen

- A real image is one produced by the **convergence** of light towards a focus
- Real images are always **inverted**
- Real images can be projected onto pieces of paper or screens
 - An example of a real image is the image formed on a cinema screen

Projecting a Real Image



A real image can be projected onto a screen

- Real images are where two **solid lines** cross in ray diagrams

Virtual Images

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Your notes

- A virtual image is defined as:

 An image that is formed when the light rays from an object do not meet but appear to meet behind the lens and cannot be projected onto a screen

- A virtual image is formed by the **divergence** of light away from a point
- Virtual images are always **upright**
- Virtual images **cannot** be projected onto a piece of paper or a screen
 - An example of a virtual image is a person's reflection in a mirror

Virtual Image in a Reflection



A reflection in a mirror is an example of a virtual image

- Virtual images are where two **dashed lines,** or **one dashed and one solid line** crosses in ray diagrams

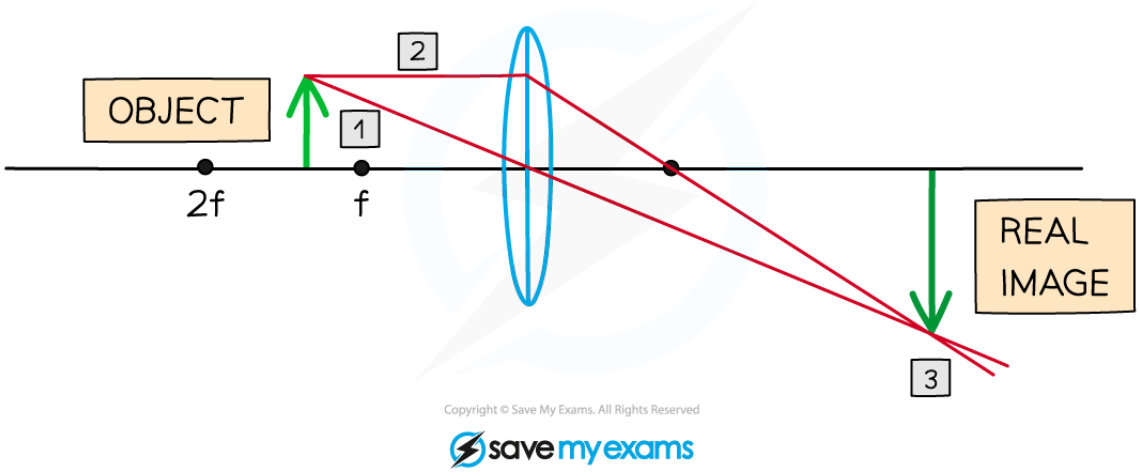
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Real Images with Converging Lenses

Your notes

- Lenses can be used to form images of objects placed in front of them
- The location (and nature) of the image can be found by drawing a ray diagram:

Object Between f and 2f



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Diagram showing the formation of a real image by a lens

1. Start by drawing a ray going from the top of the object through the centre of the lens. This ray will continue to travel in a straight line
2. Next draw a ray going from the top of the object, travelling parallel to the axis to the lens. When this ray emerges from the lens it will travel directly towards the principal focus
3. The image is found at the point where the above two rays meet

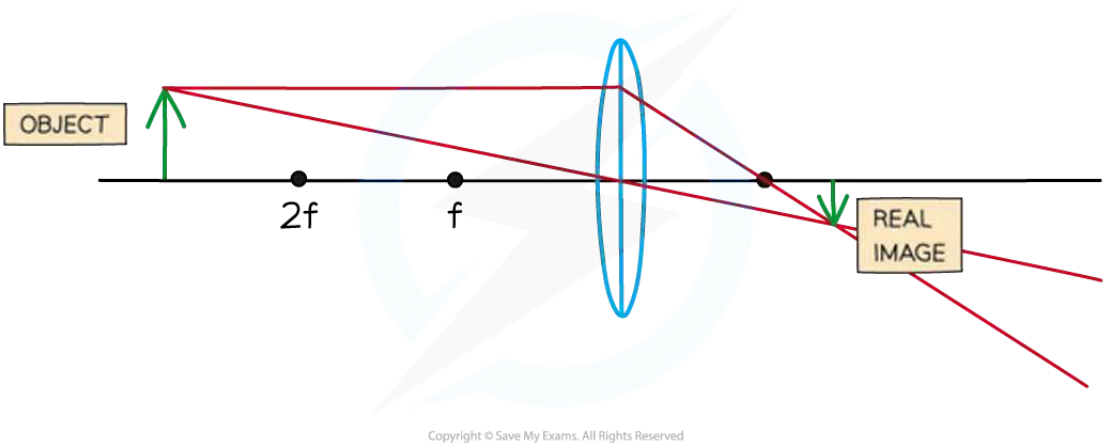
- The above diagram shows the image that is formed when the object is placed at a distance between one focal length (f) and two focal lengths (2f) from the lens
- In this case, the image is:
 - **Real**
 - **Enlarged**
 - **Inverted**

- The following diagram shows what happens when the object is more distanced – further than twice the focal length (2f) from the lens:

Object over 2f from Lens

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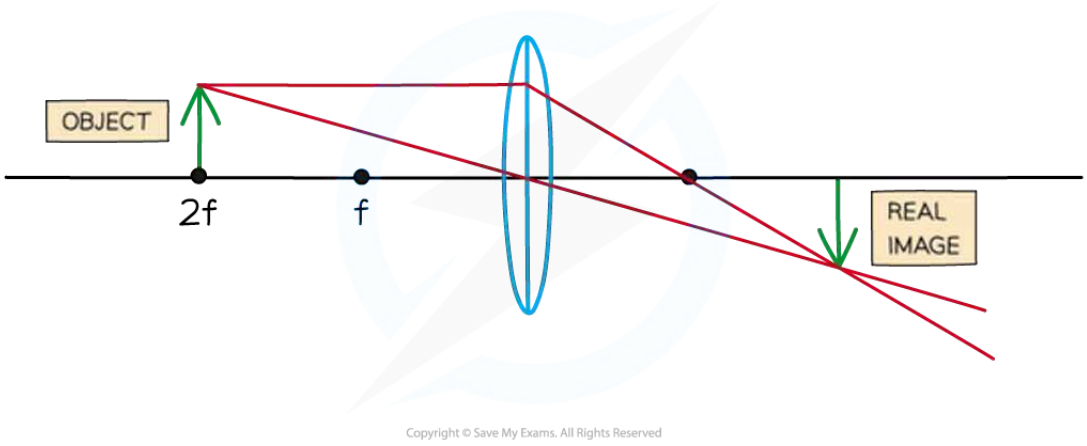


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Diagram showing the formation of a real image by a lens with the object at distance

- In this case the image is:
 - **Real**
 - **Diminished (smaller)**
 - **Inverted**
- If the object is placed at exactly twice the focal length (2f) from the lens:

Object Exactly 2f from Lens



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Diagram showing the formation of a real image with the object at 2f

- In this case the image is:
 - **Real**

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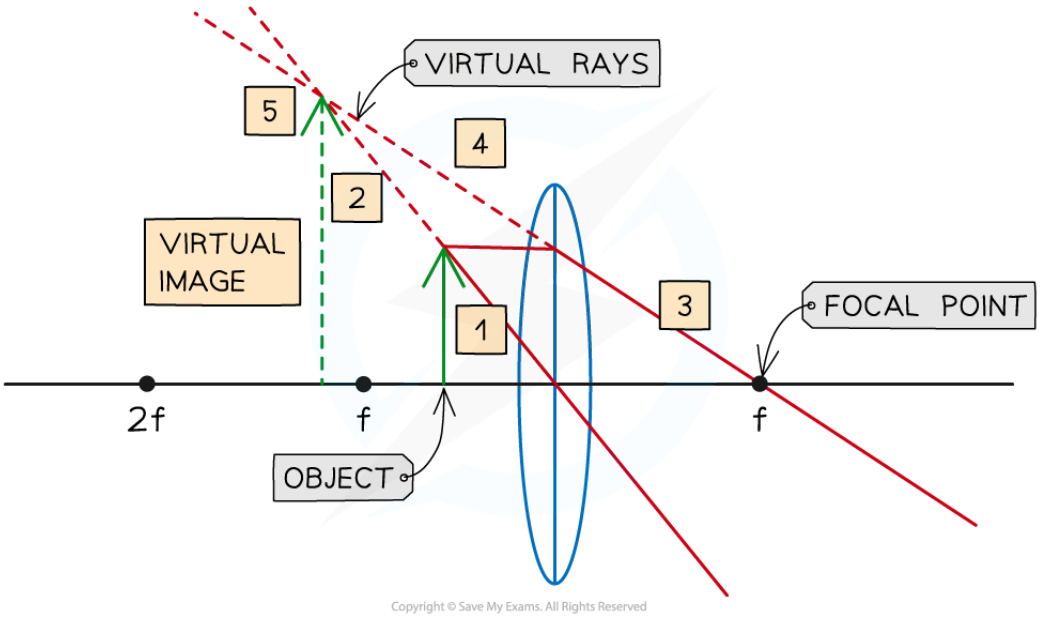
- **Same size as the object**
- **Inverted**

Your notes

Virtual Images with Converging Lenses

- A converging lens will produce a **real** image of an object which is placed at a distance **greater** than the focal length from the lens
- If the object is placed **closer** to the lens than the focal length *f* then a **virtual** image will be formed and the converging lens ray diagram will be drawn in the following way:

Object less than f from the Lens



A virtual image formed when the object is placed closer than the focal length

1. Start by drawing a ray going from the top of the object through the **centre** of the lens. This ray will continue to travel in a straight line
2. Draw a dashed line continuing this ray upwards
3. Next draw a ray going from the top of the object, travelling parallel to the axis to the lens. When this ray emerges from the lens it will travel directly through the **principal focus** *f*
4. Also, draw a dashed line continuing this ray upwards
5. The image is the line drawn from the axis to the point where the two dashed lines **meet**

- In this case, the image is:
 - **Virtual**: the light rays appear to meet when produced backwards

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- **Magnified**: the image is larger than the object
- **Upright**: the image is formed on the same side of the principal axis

- **Real** images are formed by **converging rays**
- **Virtual** images are formed by **diverging rays**


Your notes

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Linear Magnification

Your notes

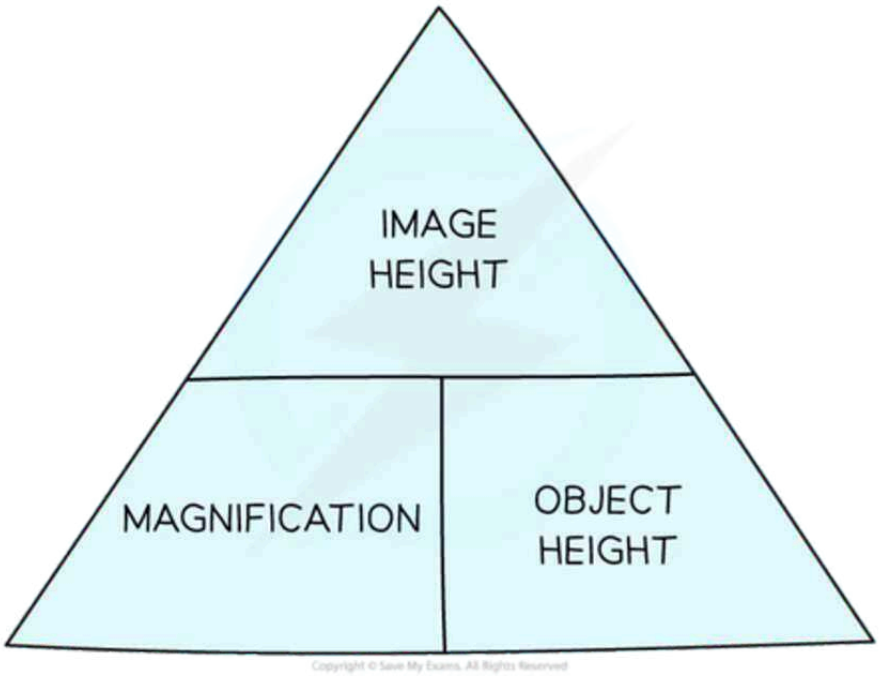
Linear Magnification

- The magnification of a lens is equal to the ratios of the image height and the object height

$$\text{magnification} = \frac{\text{image height}}{\text{object height}}$$

- This equation can be rearranged with the help of a formula triangle:

Magnification Formula Triangle



Magnification, image height and object height formula triangle

- The magnification depends on:
 - The **distance** of an object from the lens
 - The **power** of the lens
- The units for height are unimportant, provided that both the object and image are measured in the **same units**
 - For example, both in cm, or both in mm

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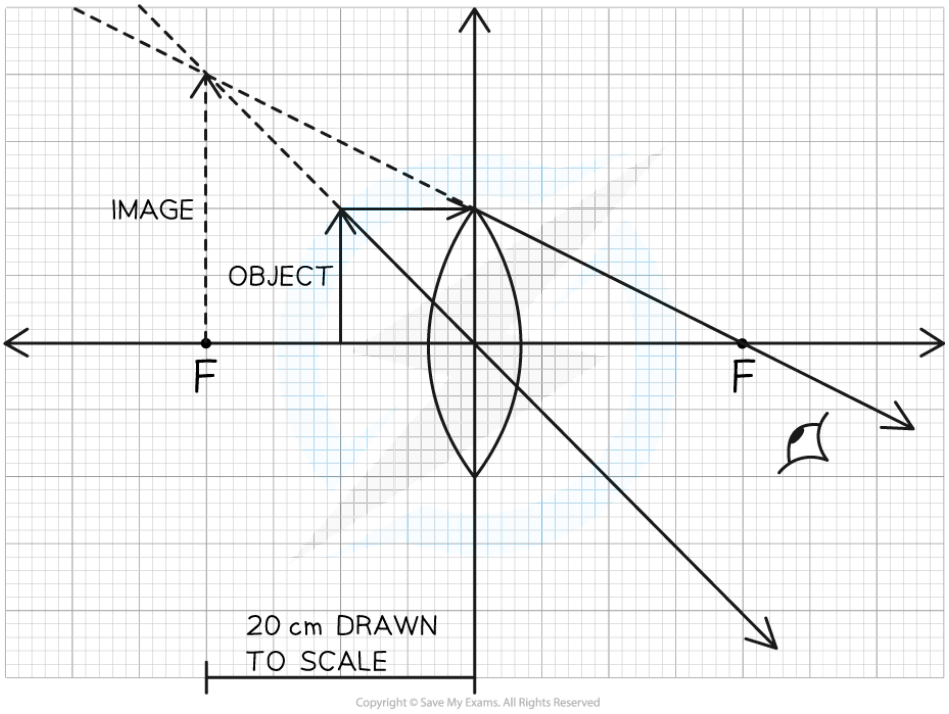
- Therefore, magnification **does not** have units as it is a **ratio**
- If the magnification is:
 - > 1, then the image is **magnified**
 - = 1, then the object and image are the **same size**
 - < 1, then the image is **diminished**


Your notes

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Worked example

A person sees an image from a magnifying glass.



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Calculate the magnification of this image. Clearly show your working on the diagram.

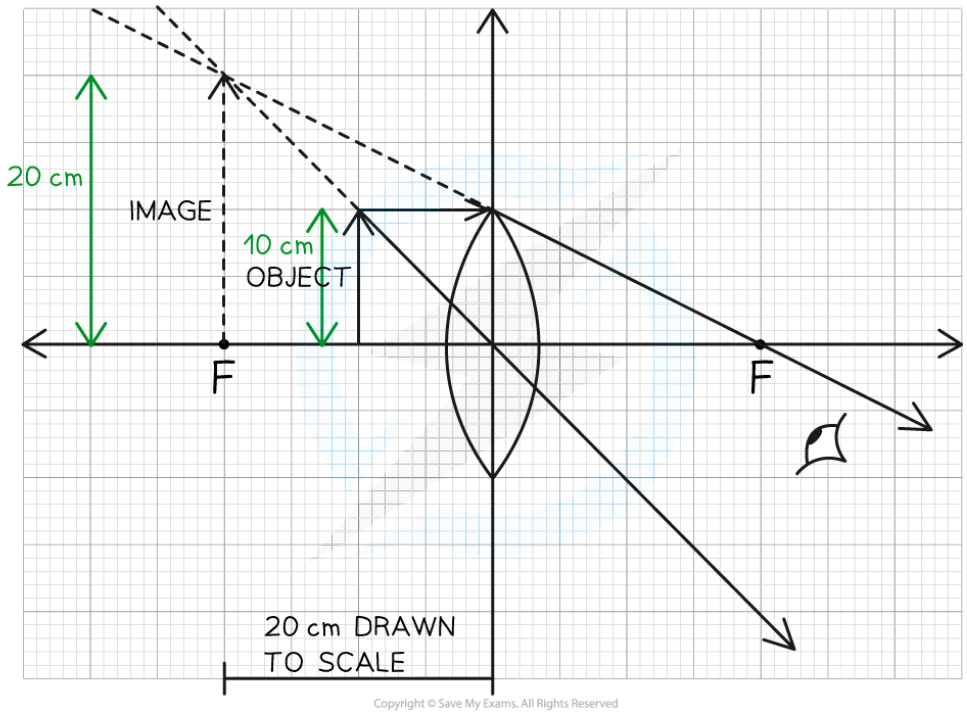
Answer:

Step 1: Measure the height of the object and image from the scale

Your notes

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Your notes



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- The object is 10 cm
- The image is 20 cm

Step 2: Substitute values into the magnification equation

$$\text{magnification} = \frac{20}{10} = 2$$

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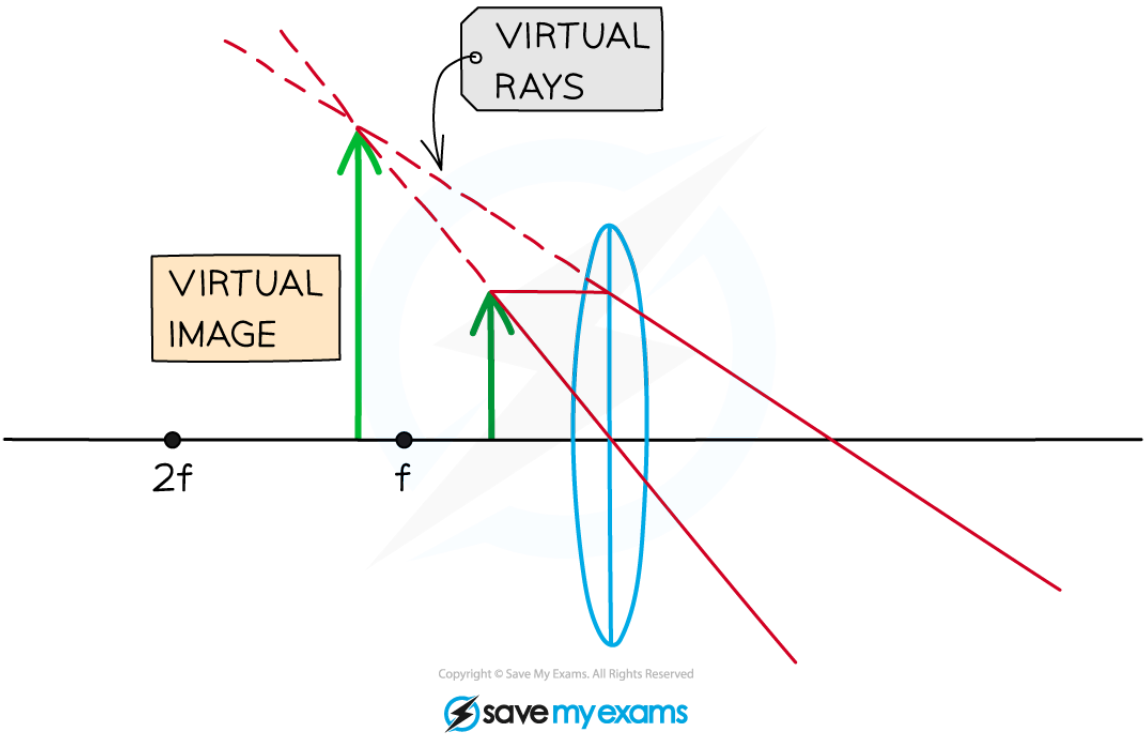
Uses of Lenses

Your notes

Magnifying Glasses

- If the object is placed closer to the lens than the focal length, the emerging rays diverge and a real image is no longer formed
- When viewed from the right-hand side of the lens, the emerging rays appear to come from a point on the left
 - This point can be found by extending the rays backwards (creating virtual rays)
- A virtual image will be seen at the point where these virtual rays cross

A Lens Close to an Object Forms a Magnified Image



A virtual image is formed by the divergence of rays from a point

- In this case the image is:
 - **Virtual**
 - **Enlarged**
 - **Upright**

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- Using a lens in this way allows it to be used as a **magnifying glass**
- When using a magnifying glass, the lens should always be held close to the object


Your notes

Correcting Sight

- Converging and diverging lenses are commonly used in glasses to correct defects of sight
 - Converging lenses can be used to correct long-sighted vision
 - Diverging lenses can be used to correct short-sighted vision

Correcting Short-Sightedness

- People who are **short-sighted** have eyes that are 'too large'
 - This means they cannot see things that are far away, and only see things that are close to them
- This is because the eye refracts the light and brings it to a focus **before** it reaches the retina
 - In other words, the focus point is in front of the retina at the back of the eye
- This can be corrected by using a concave or a **diverging lens** in front of the eye
 - This causes the light to focus further back, at the retina

Correcting Long-Sightedness

- People who are long-sighted have eyes that are 'too small'
 - This means they cannot clearly see things that are close, and can only clearly see things that are far away
- This is because the eye refracts the light rays and they are brought to a focus **beyond** the retina
 - In other words, the focus point is behind the retina at the back of the eye
- This can be corrected by using a convex or **converging lens** in front of the eye
 - This causes the light to focus further forward, at the retina

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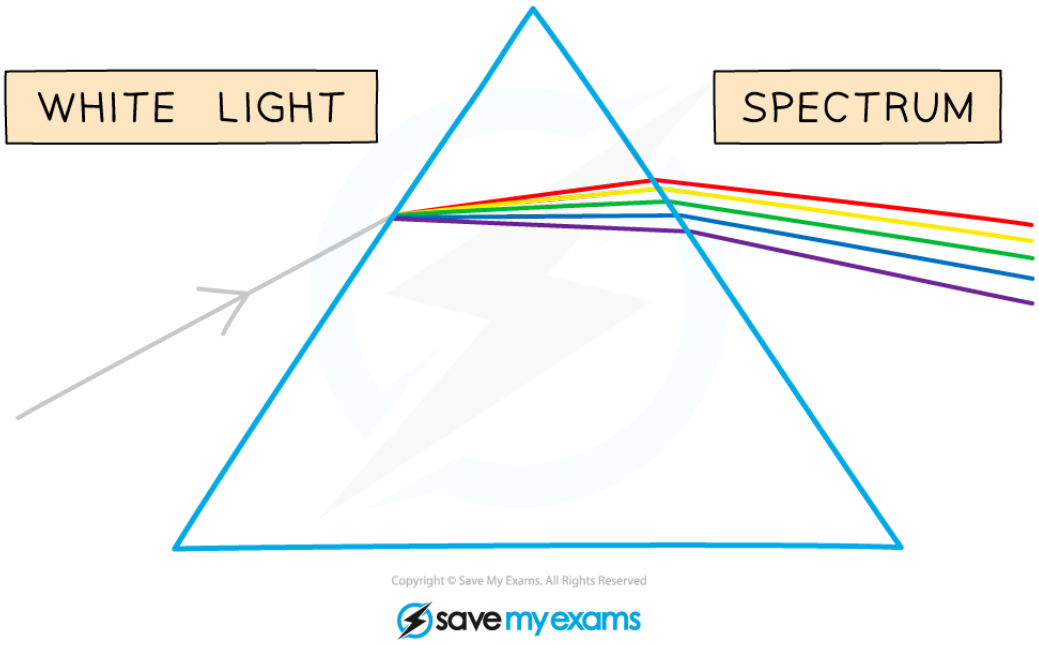
Dispersion of Light

Your notes

Dispersion of Light

- White light is a mixture of **all** the colours of the spectrum
- Each colour has a different wavelength (and frequency), making up a very narrow part of the electromagnetic spectrum
- White light may be separated into all its colours by passing it through a **prism**
 - This is done by **refraction**
 - Violet light is refracted the most, whilst red light is refracted the least
 - This splits up the colours to form a **spectrum**
- This process is similar to how a rainbow is created

Dispersion of White Light through a Prism



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White light may be separated into all its colours by passing it through a prism

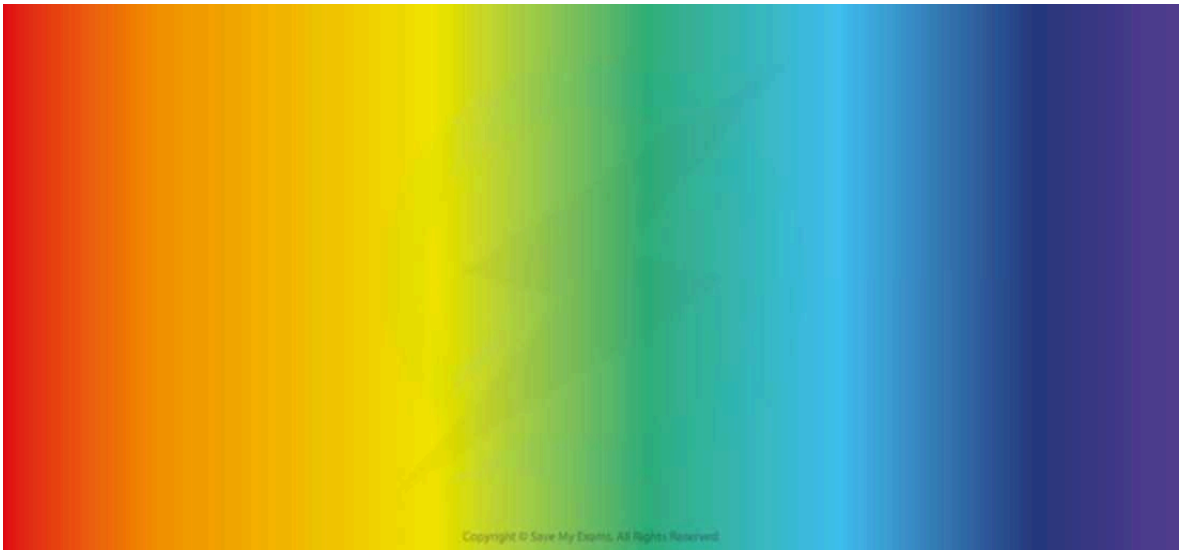
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The Visible Spectrum of Light

Your notes

- Visible light is defined as the range of wavelengths which are visible to humans
- Visible light is the **only** part of the spectrum detectable by the human eye
 - However, it only takes up 0.0035% of the **whole** electromagnetic spectrum
- In the natural world, many animals, such as birds, bees and certain fish, are able to perceive beyond visible light and can see infra-red and UV wavelengths of light
- The different colours of waves correspond to different wavelengths:
 - **Red** has the **longest** wavelength (and the lowest frequency and energy)
 - **Violet** has the **shortest** wavelength (and the highest frequency and energy)

The Spectrum of Colours of Visible Light



The colours of the visible spectrum: red has the longest wavelength; violet has the shortest

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Exam Tip

To remember the colours of the visible spectrum you could remember either:

- The name "Roy G. Biv"
- Or the saying "Richard Of York Gave Battle In Vain"

Your notes

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Cambridge O Level Physics

Your notes

3.3 Electromagnetic Spectrum

Contents

- Electromagnetic Waves
- Uses of Electromagnetic Waves
- Dangers of Electromagnetic Waves

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Electromagnetic Waves

Your notes

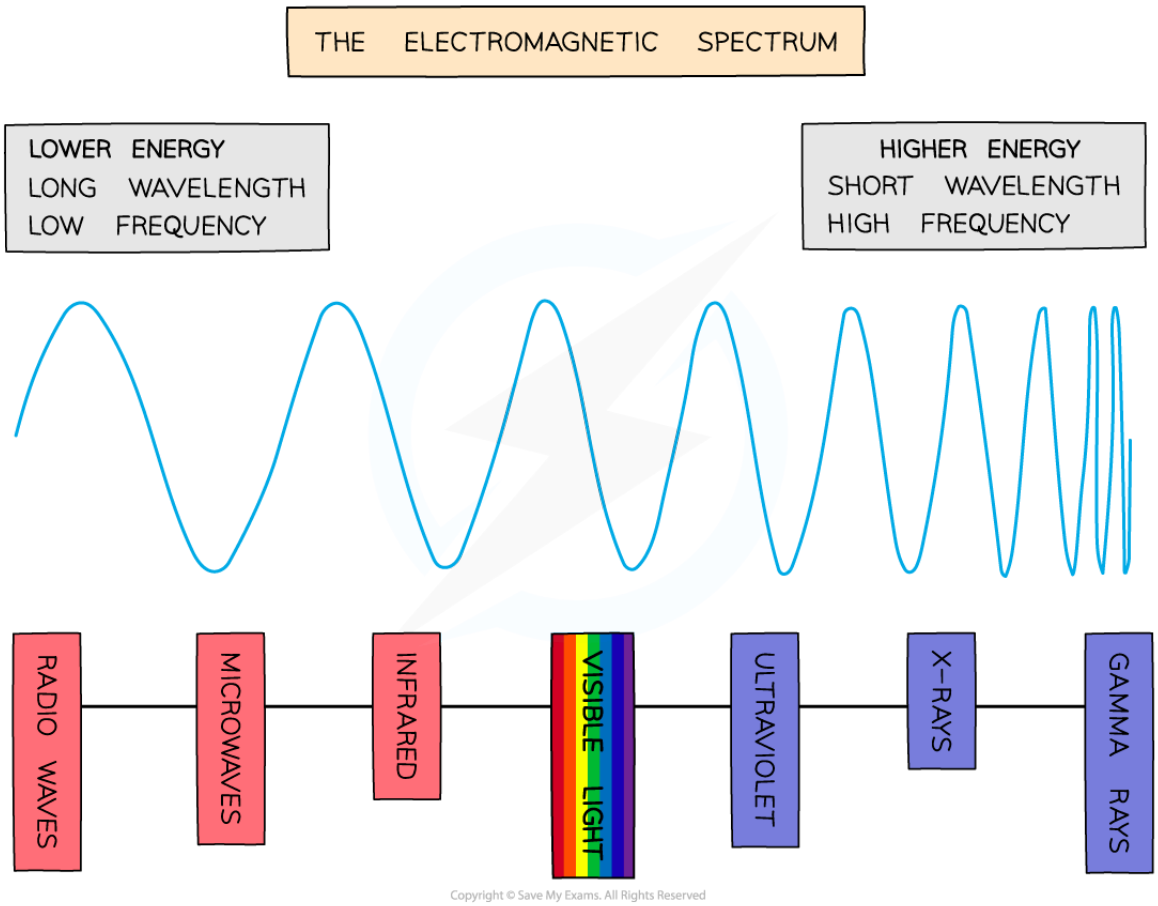
Electromagnetic Waves

- The electromagnetic spectrum is arranged in a specific order based on the wavelengths or frequencies
- The main groupings of the continuous electromagnetic (EM) spectrum in order of increasing frequency and decreasing wavelength are:
 - Radio waves
 - Microwaves
 - Infrared
 - Visible (red, orange, yellow, green, blue, indigo, violet)
 - Ultraviolet
 - X-rays
 - Gamma rays
- This order is shown in the diagram below from longest wavelength (lowest frequency) to shortest wavelength (highest frequency)

The Spectrum of Electromagnetic Waves

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Your notes



Visible light is just one small part of a much bigger spectrum: The electromagnetic spectrum

- The **higher** the **frequency**, the higher the **energy** of the radiation
- Radiation with higher energy is:
 - Highly ionising
 - Harmful to cells and tissues causing cancer (e.g. UV, X-rays, Gamma rays)
- Radiation with lower energy is:
 - Useful for communications
 - Less harmful to humans

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Exam Tip

See if you can make up a mnemonic to help you remember the EM spectrum!

One possibility is:

Raging **M**artians **I**nvaded **V**enus **U**sing **X**-ray **G**uns

The electromagnetic spectrum is usually given in order of **decreasing wavelength** and **increasing frequency** i.e. from radio waves to gamma waves

Remember:

- Radios are **big** (long wavelength)
- Gamma rays are emitted from atoms which are **very small** (short wavelength)

Your notes

Properties of Electromagnetic Waves

- Electromagnetic waves are defined as:

Transverse waves that transfer energy from the source of the waves to an absorber

- All electromagnetic waves share the following properties:
 - They are all **transverse**
 - They can all travel through a **vacuum**
 - They all travel at the **same speed** in a vacuum
- The 7 types of electromagnetic waves together form a **continuous spectrum**

The Speed of Electromagnetic Waves

- The speed of electromagnetic waves in a vacuum is

$$3.0 \times 10^8 \text{ m/s}$$

- This is approximately the same speed as electromagnetic waves in air

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Uses of Electromagnetic Waves


Your notes

Uses of Electromagnetic Waves

- Electromagnetic waves have a variety of uses and applications

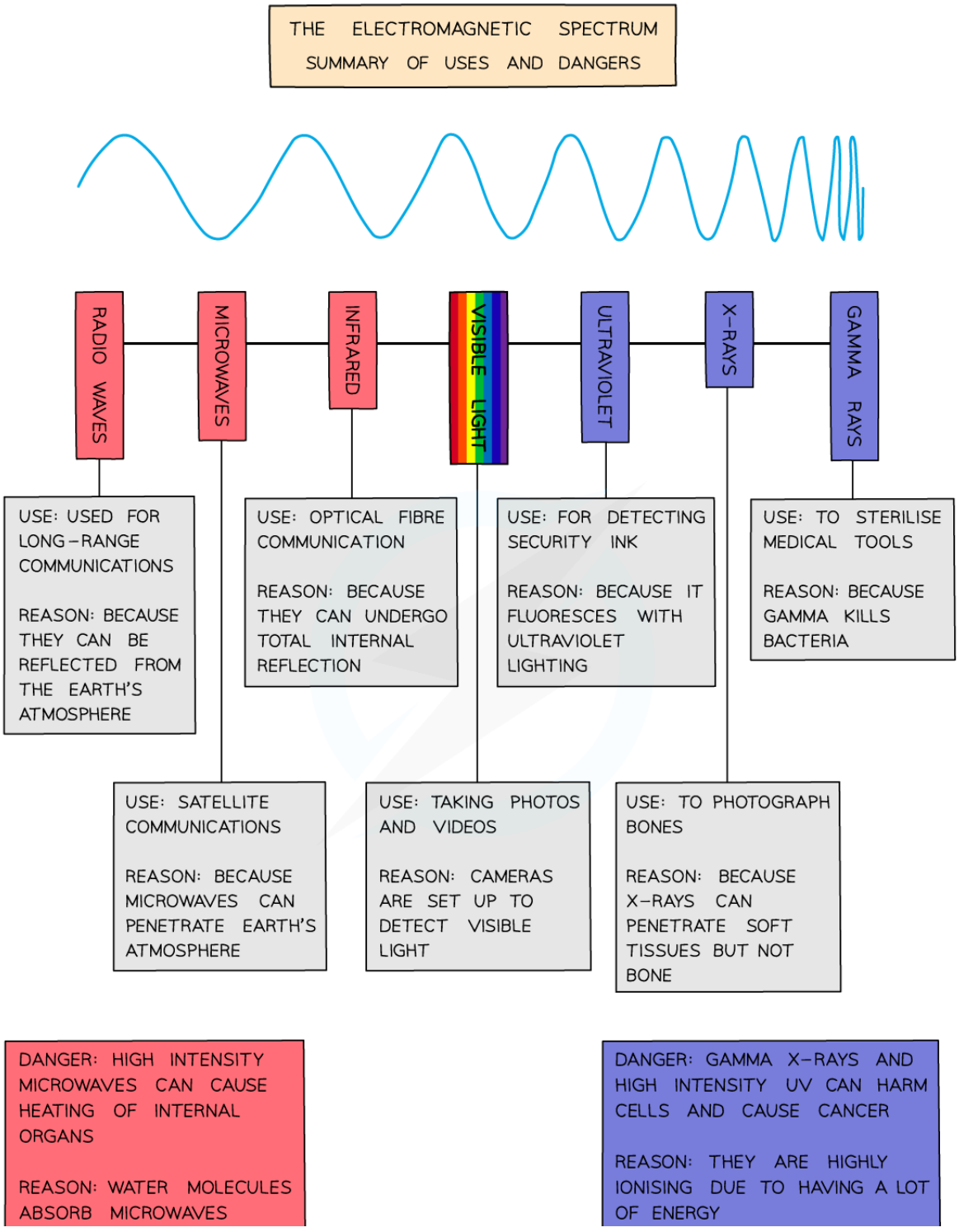
Table of Applications of EM Waves

Wave	Use
Radio	▪ Communication (radio and TV) ▪ Astronomy
Microwave	▪ Heating food (microwave ovens) ▪ Communication (WiFi, mobile phones, Bluetooth, satellite TV, satellites)
Infrared	▪ Remote controls ▪ Fibre optic communications ▪ Thermal imaging (medicine and industry) ▪ Night vision ▪ Heating and cooking ▪ Motion sensors (for security alarms) ▪ Electrical heaters ▪ Infrared cameras
Visible light	▪ Vision ▪ Photographs/videos
Ultraviolet	▪ Security markings (fluorescence) ▪ Detecting counterfeit bank notes ▪ Sterilising water
X-rays	▪ Medical (and dental) imaging ▪ Security scanners (at airports etc.) ▪ Killing cancerous cells ▪ Engineering applications (detecting cracks in metals)
Gamma rays	▪ Sterilising food ▪ Sterilising medical equipment ▪ Detecting & treating cancerous cells ▪ Engineering applications (detecting cracks in metals)

A summary of the Uses and Dangers of EM Waves

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STRONGLY

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Your notes

Uses and dangers of the electromagnetic spectrum

Radio Waves & Microwaves

- These two parts of the spectrum share a lot of similarities and applications
 - Their main uses concern wireless communication – in fact, many things that people often assume use radio waves actually use microwaves (e.g. WiFi, radar, mobile phones, satellite communications)
- At very high intensities microwaves can also be used to heat things
 - This is what happens in a microwave oven

Infrared

- Infrared is emitted by warm objects and can be detected using special cameras (thermal imaging cameras). These can be used in industry, in research and also in medicine
- Many security cameras are capable of seeing slightly into the infrared part of the spectrum and this can be used to allow them to see in the dark
 - Infrared lights are used to illuminate an area without being seen, which is then detected using the camera
- Remote controls also have small infrared LEDs that can send invisible signals to an infrared receiver on a device such as a TV
- Infrared travels down fibre optic cables more efficiently than visible light, and so most fibre optic communication systems use infrared

Visible

- Visible light is the only part of the electromagnetic spectrum that the human eye can see
- The human eye can detect wavelengths from 750 nanometres (red light) up to 380 nanometres (violet light)

Ultraviolet

- Ultraviolet is responsible for giving you a sun tan, which is your body's way of protecting itself against the ultraviolet
- When certain substances are exposed to ultraviolet, they absorb it and re-emit it as visible light (making them glow)
 - This process is known as fluorescence
 - Fluorescence can be used to secretly mark things using special ink – in fact, most bank notes have invisible fluorescent markings on them

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- Fluorescent light bulbs also use this principle to emit visible light


Your notes

X-rays

- The most obvious use of x-rays is in medicine
- X-rays are able to pass through most body tissues but are absorbed by the denser parts of the body, such as bones
 - When exposed to x-rays, the bones absorb the x-rays, leaving a shadow which can be seen using a special x-ray detector or photographic film

Gamma Rays

- Gamma rays are very dangerous and can be used to kill cells and living tissue
- This property can be utilised in both cancer detection and treatment
 - If these gamma rays are carefully aimed at cancerous tissue, they can be very effective at destroying the cancerous cells
- Gamma rays can also be used to sterilise food and medical equipment by killing off the bacteria

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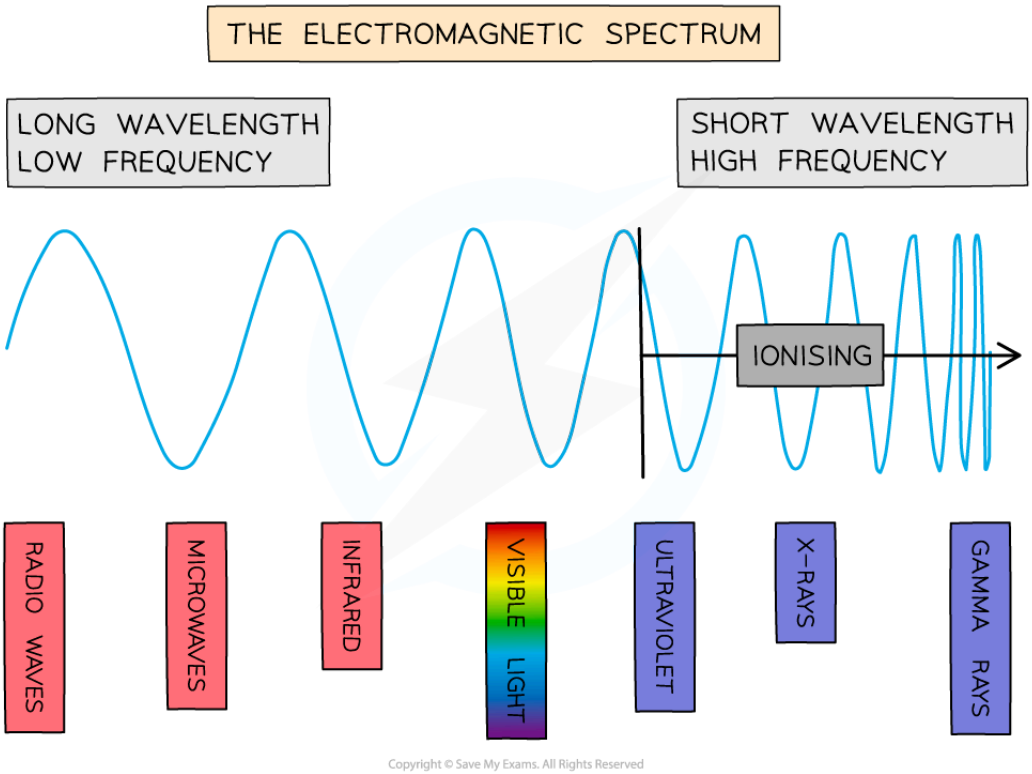
Dangers of Electromagnetic Waves

Your notes

Dangers of Electromagnetic Waves

- As the frequency of electromagnetic (EM) waves increases, so does the energy
- Beyond the visible part of the spectrum, the energy becomes large enough to **ionise** atoms
- As a result of this, the danger associated with EM waves increases along with the frequency
 - The **shorter** the wavelength, the more **ionising** the radiation
 - Although the **intensity** of a wave also plays a very important role

Ionising Region of Electromagnetic Spectrum



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Ultraviolet, X-rays and gamma rays can all ionise atoms

- Because of ionisation, ultraviolet waves, X-rays and gamma rays can have **hazardous** effects on human body tissue
 - The effects depend on the type of radiation and the size of the dose
- They can damage cells and cause mutations, making them cancerous

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- In general, electromagnetic waves become more dangerous the **shorter** their wavelength
 - For example, radio waves have no known harmful effects whilst gamma rays can cause cancer and are regarded as extremely dangerous
- The main risks associated with electromagnetic waves are summarised in the table below:


Your notes

Dangers of EM Waves Table

Wave	Danger
Radio	▪ No known danger
Microwave	▪ Possible heat damage to soft tissues and internal organs
Infrared	▪ Skin burns
Visible light	▪ Eye damage
Ultraviolet	▪ Eye damage ▪ Sunburn ▪ Skin cancer
X-rays	▪ Kills cells ▪ Mutations ▪ Cancer
Gamma rays	▪ Kills cells ▪ Mutations ▪ Cancer

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Cambridge O Level Physics

Your notes

3.4 Sound

Contents

- Sound Waves
- Properties of Sound Waves
- Reflection of Sound Waves
- Measuring the Speed of Sound
- Ultrasound

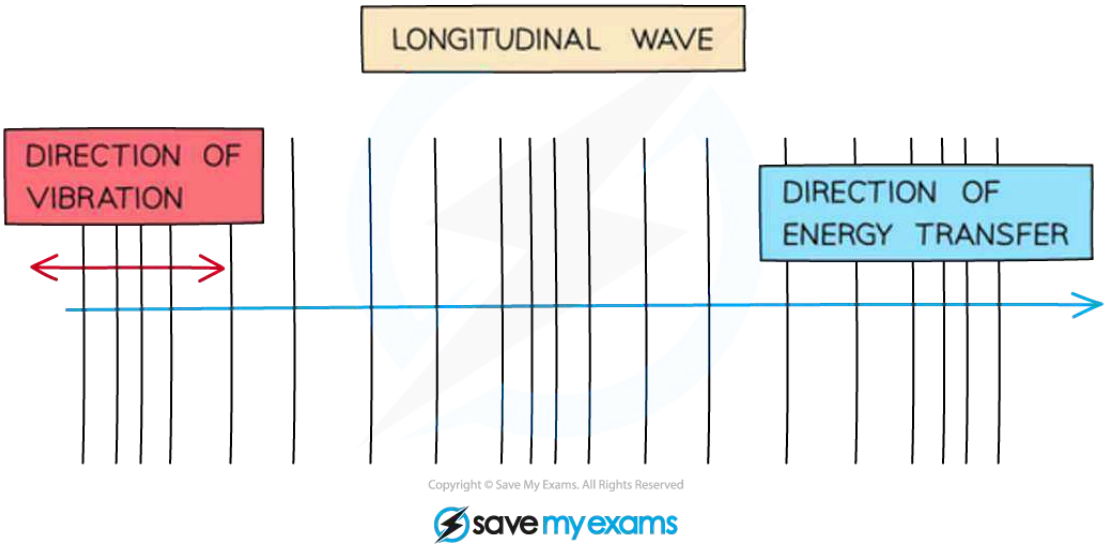
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Sound Waves

Your notes

Describing Sound

- Sound waves are produced by **vibrating** sources
- When a sound wave comes into contact with a solid, those vibrations can be **transferred** to the solid
 - For example, sound waves can cause a drinking glass to vibrate
 - If the glass vibrates too much the movement causes the glass to shatter



Sound waves are longitudinal: the molecules vibrate in the same direction as the energy transfer

- Sound waves require a **medium** to travel through
 - This means that if there are no molecules, such as in a vacuum, then the sound can't travel through it
- The range of frequencies a human can hear is **20 Hz to 20 000 Hz**

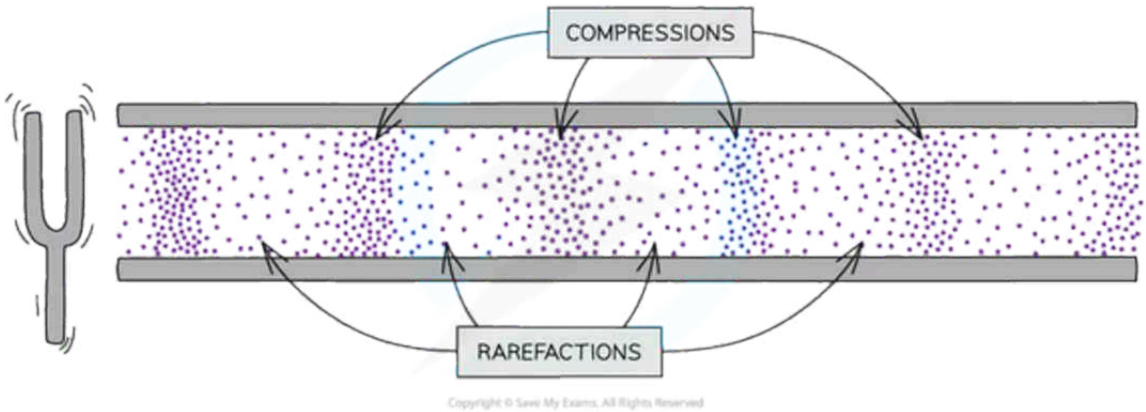
Compression & Rarefaction

- Longitudinal waves consist of **compression** and **rarefactions**:
 - A **compression** is a region of higher density i.e. a place where the molecules are bunched together
 - A **rarefaction** is a region of lower density i.e. a place where the molecules are spread out

Compressions and Rarefactions of Air in a Column

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Your notes

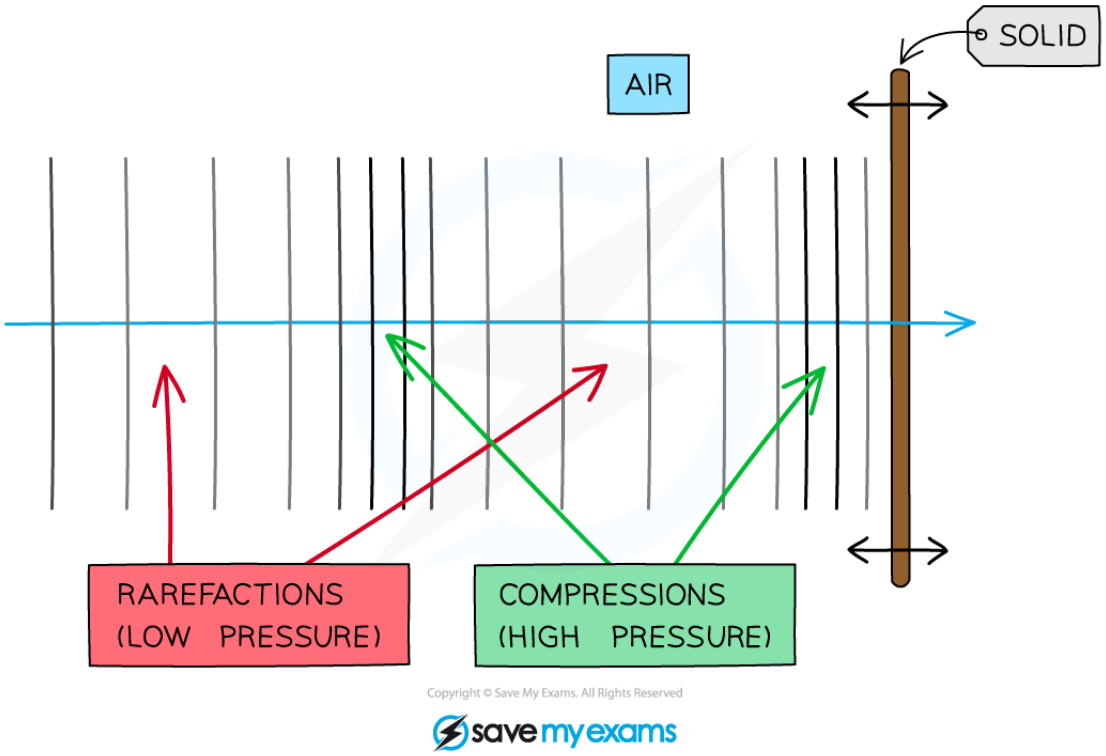


Sound is a longitudinal wave consisting of compressions and rarefactions – these are areas where the pressure of the air varies with the wave

- These compressions and rarefactions cause changes in pressure, which vary in time with the wave
 - Therefore, sound is a type of **pressure wave**
- When the waves hit a solid, the variations in pressure cause the surface of the solid to **vibrate** in sync with the sound wave

Compressions and Rarefactions of Sound Reflecting from a Solid

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When sound waves hit a solid, the fluctuating pressure causes the solid to vibrate

Exam Tip

When describing compressions and rarefactions, make sure to use the correct terms. It is best to refer to them as regions of high and low densities of particles instead of the particles are more 'bunched up' or 'far apart', as this is too vague and not very scientific!

Your notes

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Investigating Sound in a Vacuum

Your notes

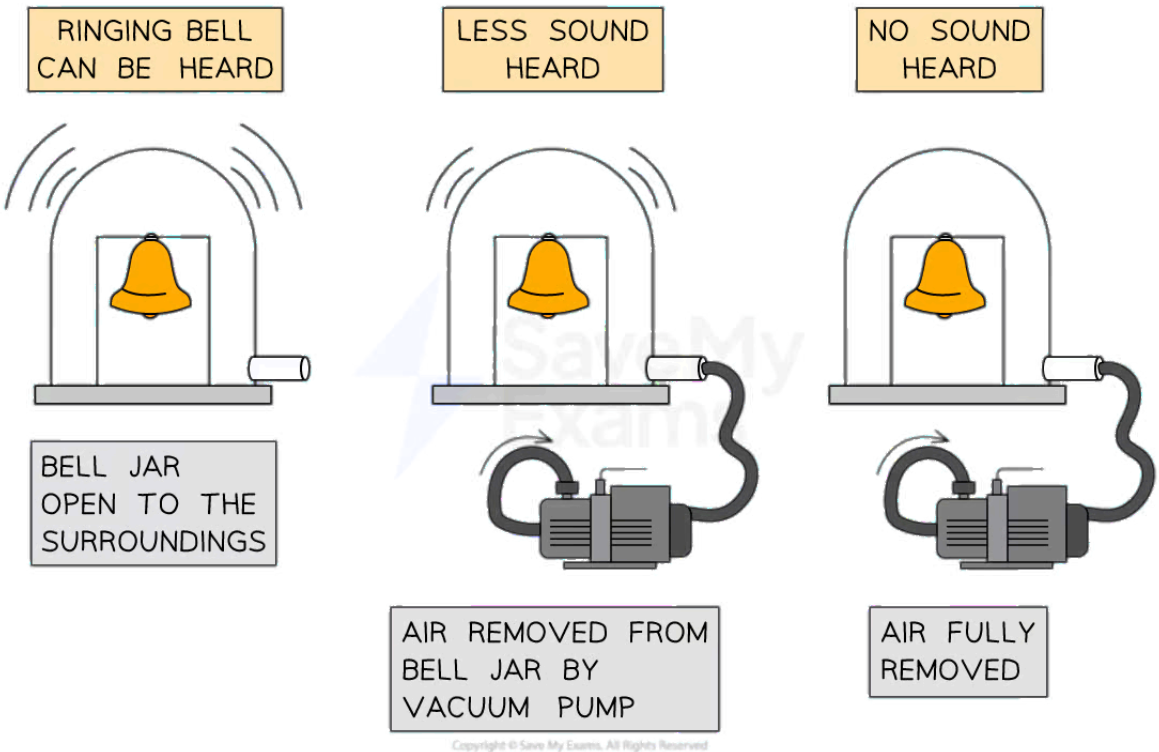
Sound Waves in a Vacuum

- Sound waves are **longitudinal** waves
 - All longitudinal waves require a **medium** through which to travel
- A vacuum is a region of space that does not contain air (or any other matter)
 - This means that, in a vacuum, there is no medium for sound waves
 - So sound waves **cannot** travel in a **vacuum**

Using a Bell Jar

- This can be easily demonstrated using a piece of equipment called a **bell jar**
 - This is a glass container from which air can be pumped out, creating a vacuum (or nearly a vacuum)
- A sound-emitting object is used, such as a battery-operated ringing bell or alarm
- This is placed in a bell jar, which still contains air
 - The ringing bell can be heard despite the bell jar's glass walls
- However, as the air begins being pumped out, the volume of the sound heard starts decreasing
- When the air is completely removed from the bell jar, the ringing bell cannot be heard at all

Sound in a Bell Jar Demonstration



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In the absence of air, sound waves are unable to travel and leave the bell jar

Exam Tip

It is very difficult to make a perfect vacuum. This means that you may well still hear a very faint ringing in this experiment, even when as much air as possible is removed from the jar.

Your notes

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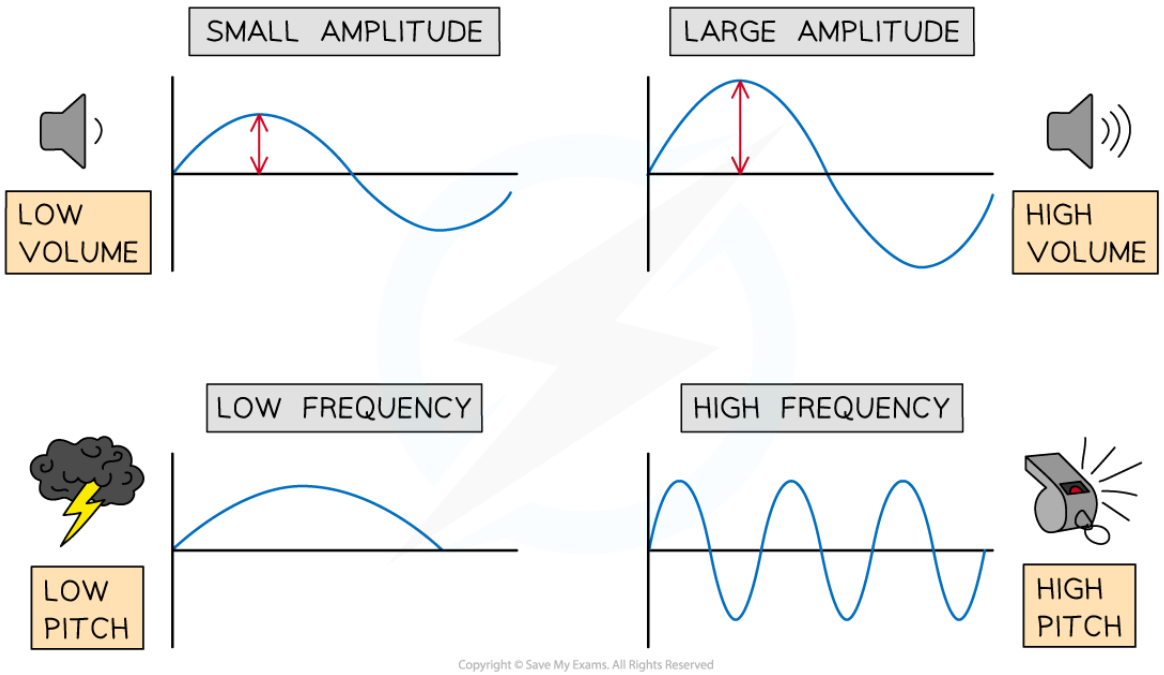
Properties of Sound Waves

Your notes

Pitch & Loudness

- The frequency of a sound wave is related to its **pitch**
 - Sounds with a **high** pitch have a **high** frequency (or short wavelength)
 - Sounds with a **low** pitch have a **low** frequency (or long wavelength)
- The amplitude of a sound wave is related to its **volume**
 - Sounds with a **large** amplitude have a **high** volume
 - Sounds with a **small** amplitude have a **low** volume

Graphs of Different Amplitudes & Frequencies



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The amplitude of a wave determines the volume of the sound and the frequency determines the pitch

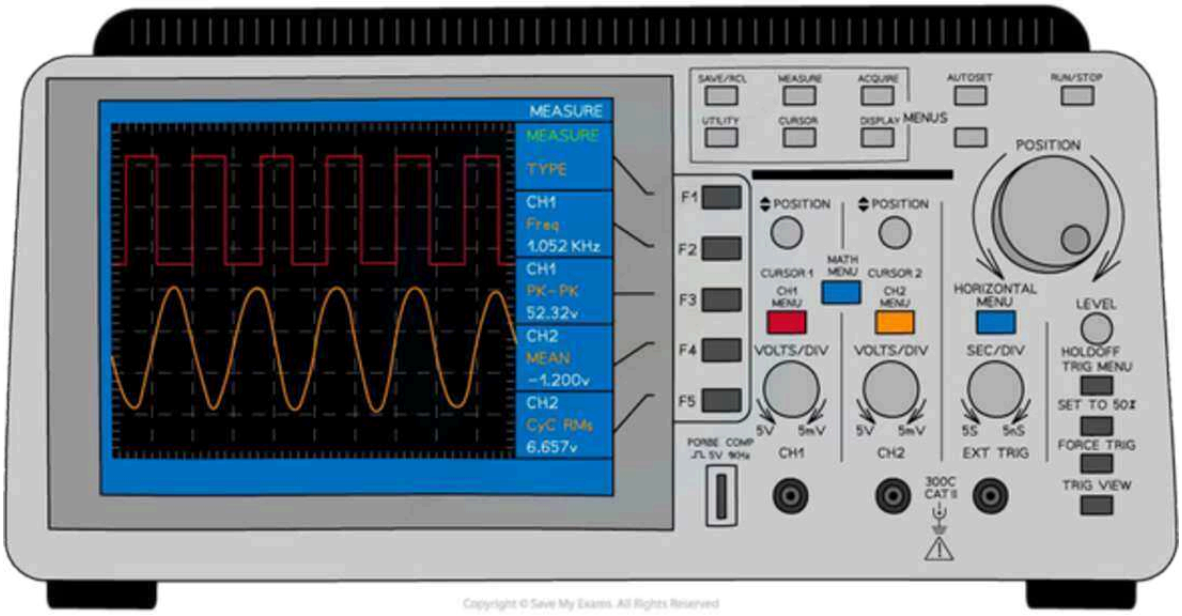
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Different Sound Sources

Your notes

- An **oscilloscope** is a device that can be used to study a rapidly **changing signal**, such as:
 - A **sound wave**
 - An **alternating current**

Oscilloscope



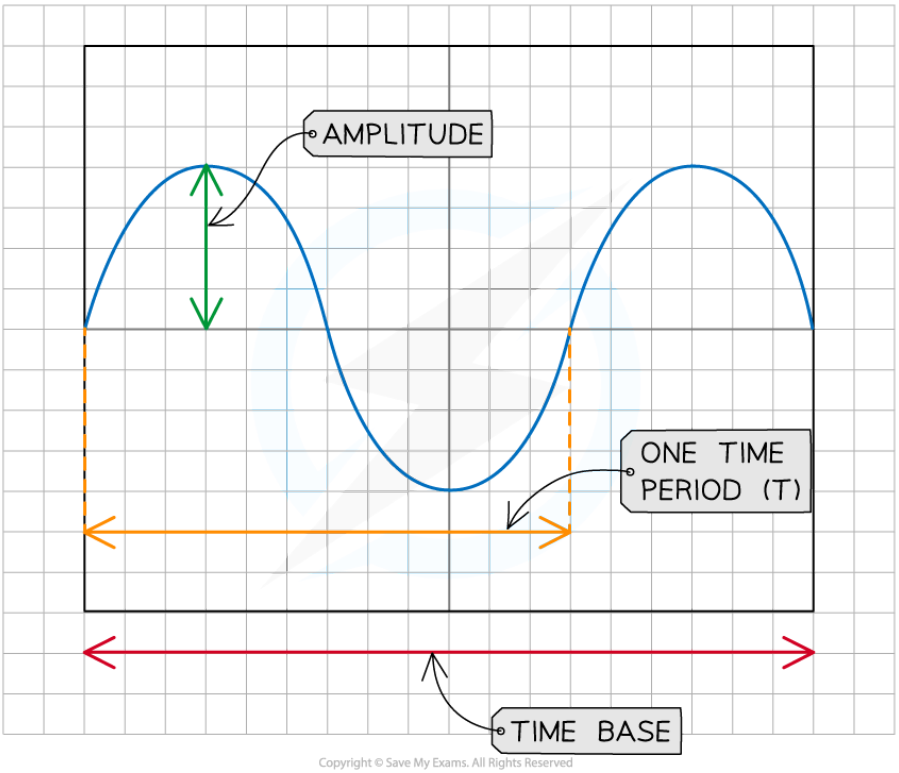
Oscilloscopes have lots of dials and buttons, but their main purpose is to display and measure changing signals like sound waves and alternating current

- When a microphone is connected to an oscilloscope, the (longitudinal) sound wave is displayed as though it were a transverse wave on the screen
- The **time base** (like the 'x-axis') is used to measure the **time period** of the wave

A Soundwave Depicted as a Transverse Wave on an Oscilloscope

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Your notes



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A sound wave is displayed as though it were a transverse wave on the screen of the oscilloscope. The time base can be used to measure a full time period of the wave cycle

- The height of the wave (measured from the centre of the screen) is related to the **amplitude** of the sound
- The number of entire waves that appear on the screen is related to the **frequency** of the wave
 - If the frequency of the sound wave **increases**, **more** waves are displayed on screen

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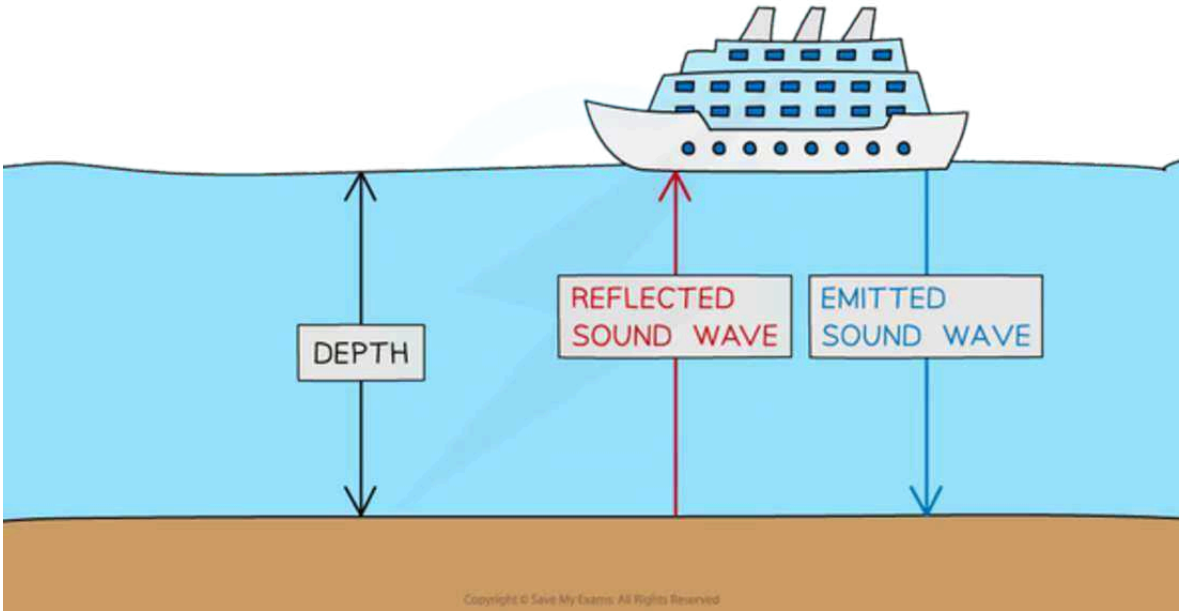
Reflection of Sound Waves

Your notes

Echoes

- Sound waves **reflect** off hard surfaces
 - The reflection of a sound wave is called an **echo**
- Echo sounding can be used to measure depth or to detect objects underwater
 - A sound wave can be transmitted from the surface of the water
 - The sound wave is reflected off the bottom of the ocean
- The time it takes for the sound wave to return is used to calculate the depth of the water
 - This is the distance to the ocean floor plus the distance for the wave to return
 - The distance the wave travels is twice the depth of the ocean

Ship using Radar



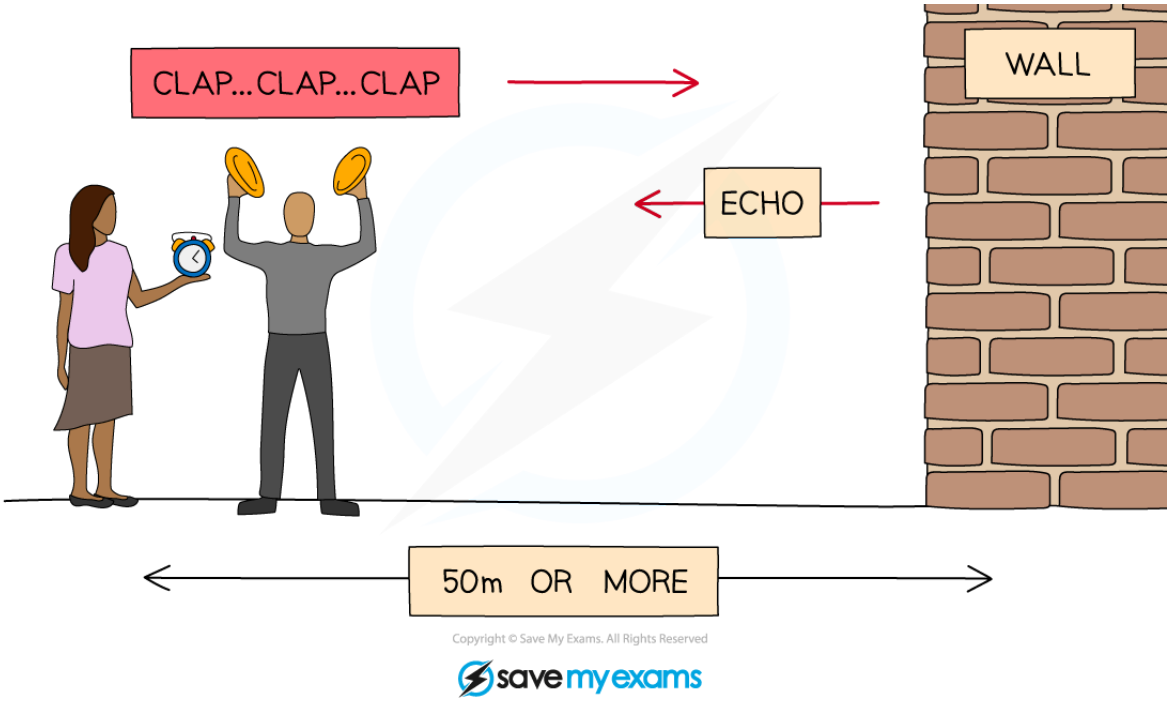
Echo sounding is used to determine water depth

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Investigating the Reflection of Sound Waves

Your notes

Using Echoes to Measure the Speed of Sound



Measuring the speed of sound using echoes

1. A person stands about 50 m away from a wall (or cliff) using a **trundle wheel** to measure this distance
2. The person claps **two wooden blocks** together and listens for the echo
3. A second person has a **stopwatch** and starts timing when they hear one of the claps and stops timing when they hear the echo
4. The process is then repeated 20 times and an average time calculated
5. The distance travelled by the sound between each clap and echo will be (2 × 50) m
6. The speed of sound can be calculated from this distance and the time using the equation:

$$\text{speed of sound} = \frac{2 \times \text{distance to wall}}{\text{time taken}}$$

$$v = \frac{2d}{t}$$

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Measuring the Speed of Sound

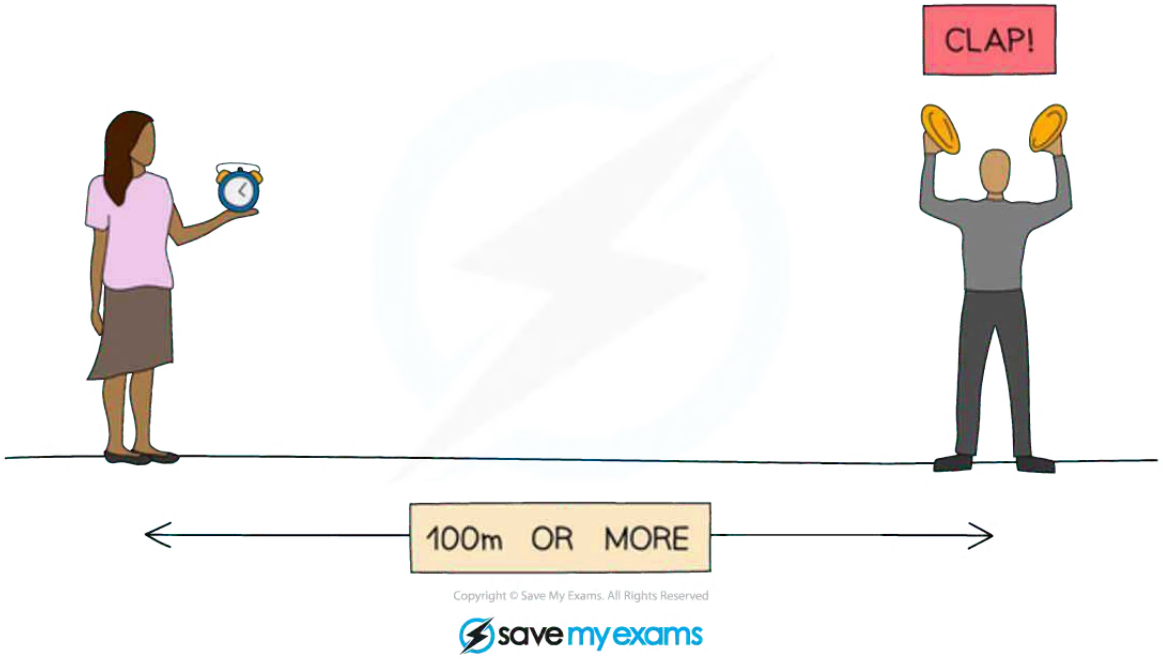
Your notes

Measuring the Speed of Sound

- There are several experiments that can be carried out to determine the speed of sound
- Three methods are described below
 - The apparatus for each experiment is given in **bold**

Method 1: Measuring Sound Between Two Points

Measuring the Speed of Sound Using a Loud Noise



Measuring the speed of sound directly between two points

1. Two people stand a distance of around 100 m apart
2. The distance between them is measured using a **trundle wheel**
3. One person has **two wooden blocks**, which they bang together above their head
4. The second person has a **stopwatch** which they start when they see the first person banging the blocks together and stops when they hear the sound
5. This is then repeated several times and an average value is taken for the time
6. The speed of sound can then be calculated using the equation:

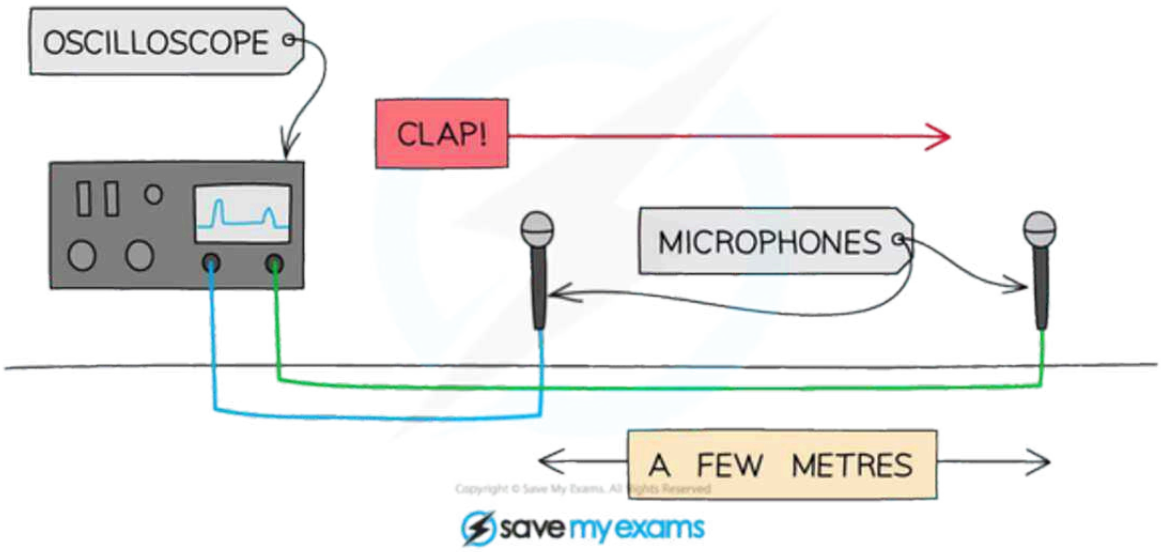
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$$\text{speed of sound} = \frac{\text{distance travelled}}{\text{time taken}}$$

Your notes

Method 2: Using an Oscilloscope

Measuring the Speed of Sound Using Microphones



Measuring the speed of sound using an oscilloscope

1. Two **microphones** are connected to an **oscilloscope** and placed about 5 m apart using a **tape measure** to measure the distance
2. The oscilloscope is set up so that it triggers when the first microphone detects a sound, and the time base is adjusted so that the sound arriving at both microphones can be seen on the screen
3. Two wooden blocks are used to make a large clap next to the first microphone
4. The oscilloscope is then used to determine the time at which the clap reaches each microphone and the time difference between them
5. This is repeated several times and an average time difference calculated
6. The speed can then be calculated using the equation:

$$\text{speed of sound} = \frac{\text{distance between microphones}}{\text{time between peaks}}$$

Measuring Wave Speed in Water

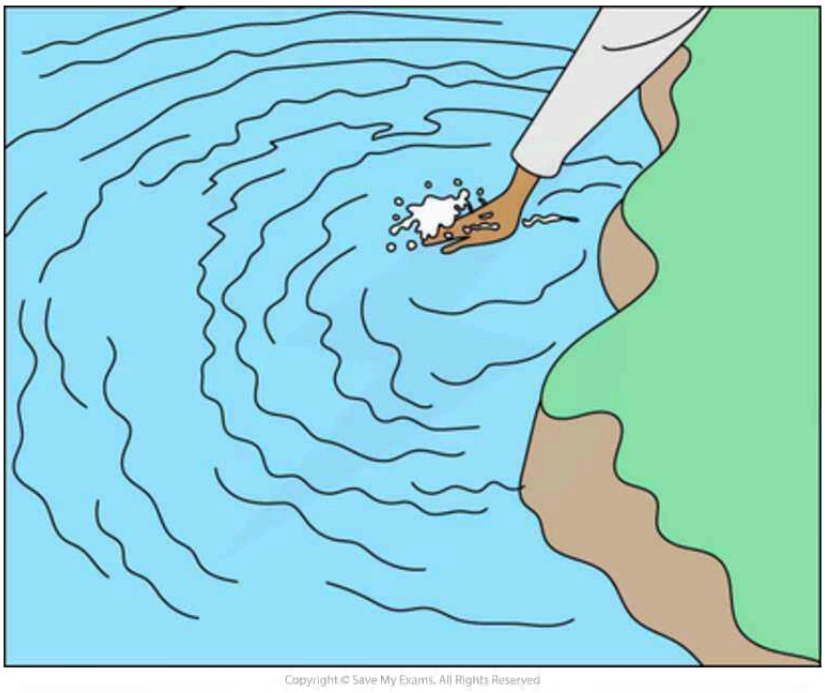
- Ripples on water surfaces are used to model transverse waves

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Your notes

- The speed of these water waves can be measured

Ripples on Water


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Creating ripples in water

1. Choose a calm flat water surface such as a lake or a swimming pool
2. Two people stand a few metres apart using a **tape measure** to measure this distance
3. One person counts down from three and then disturbs the water surface (using their hand, for example) to create a ripple
4. The second person then starts a **stopwatch** to time how long it takes for the first ripple to get to them
5. The experiment is then repeated 10 times and an average value for the time is calculated
6. The average time and distance can then be used to calculate the wave speed using the equation:

$$\text{average speed} = \frac{\text{distance moved}}{\text{time taken}}$$

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Exam Tip

When you are answering questions about methods to measure waves, the question could ask you to comment on the accuracy of the measurements

- In the case of measuring the speed of sound:
 - Method 2 is the **most** accurate because the timing is done automatically
 - Method 1 is the **least** accurate because the time interval is very short

Whilst this may not be too important when giving a method, you should be able to explain why each method is accurate or inaccurate and suggest ways of making them better (for example, use greater distances)

- For example, if a manual stopwatch is being used there could be variation in the time measured which can be up to 0.2 seconds due to a person's reaction time
- The time interval could be as little as 0.3 seconds for sound travelling in air
- This means that the variation due to the stopwatch readings has a big influence on the results and they may not be reliable


Your notes

Speed of Sound in Air

- Sound waves travel at a speed of about 340 m/s in air at room temperature
 - The higher the air temperature, the greater the speed of sound
- The speed of sound in air varies from **330 – 350 m/s**

Speed of Sound in Materials

- Sound travels at different speeds in different mediums:
 - Sound travels **fastest in solids**
 - Sound travels **slowest in gases**
- Some typical speeds of sound in solids, liquids and gases are:
 - Solids ≈ 5000 m/s
 - Liquids ≈ 1500 m/s
 - Gases ≈ 350 m/s

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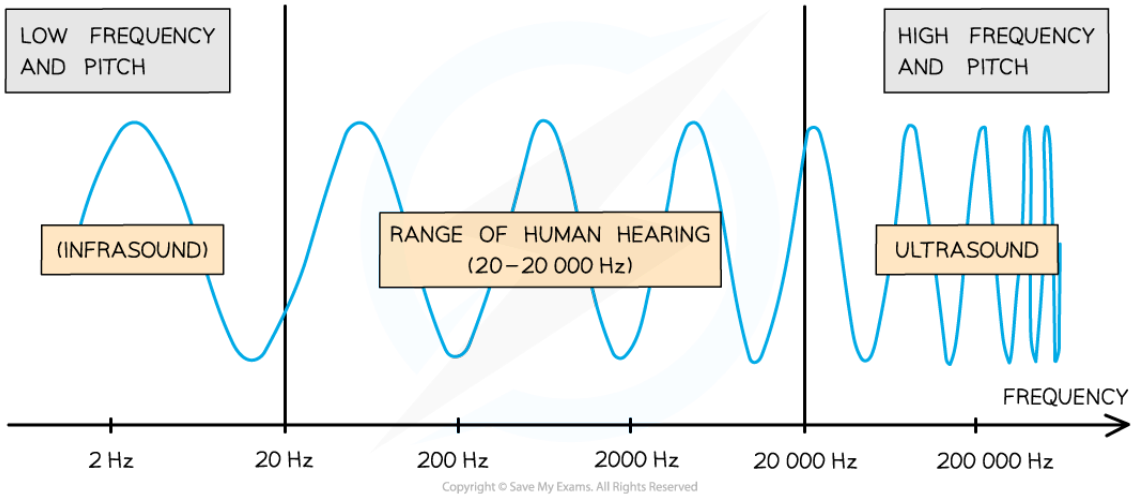
Ultrasound

Your notes

Ultrasound

- Humans can hear sounds between about 20 Hz and 20 000 Hz in frequency (although this range decreases with age)

Infrasound & Ultrasound



Humans can hear sounds between 20 and 20 000 Hz

- **Ultrasound** is the name given to sound waves with a frequency greater than 20 000 Hz

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Uses of Ultrasound

Your notes

- When ultrasound reaches a boundary between two media, some of the waves are partially reflected
- The remainder of the waves continue through the material and are transmitted
- Ultrasound transducers are able to:
 - **Emit** ultrasound
 - **Receive** ultrasound
- The time taken for the reflections to reach a detector can be used to determine how far away a boundary is
 - This is because ultrasound travels at different speeds through different media
- This is by using the speed, distance, time equation

$$\text{average speed} = \frac{\text{distance moved}}{\text{time taken}}$$

- Where:
 - v = speed in metres per second (m/s)
 - s = distance in metres (m)
 - t = time in seconds (s)
- This allows ultrasound waves to be used for both **medical** and **industrial** imaging

Ultrasound in Medicine

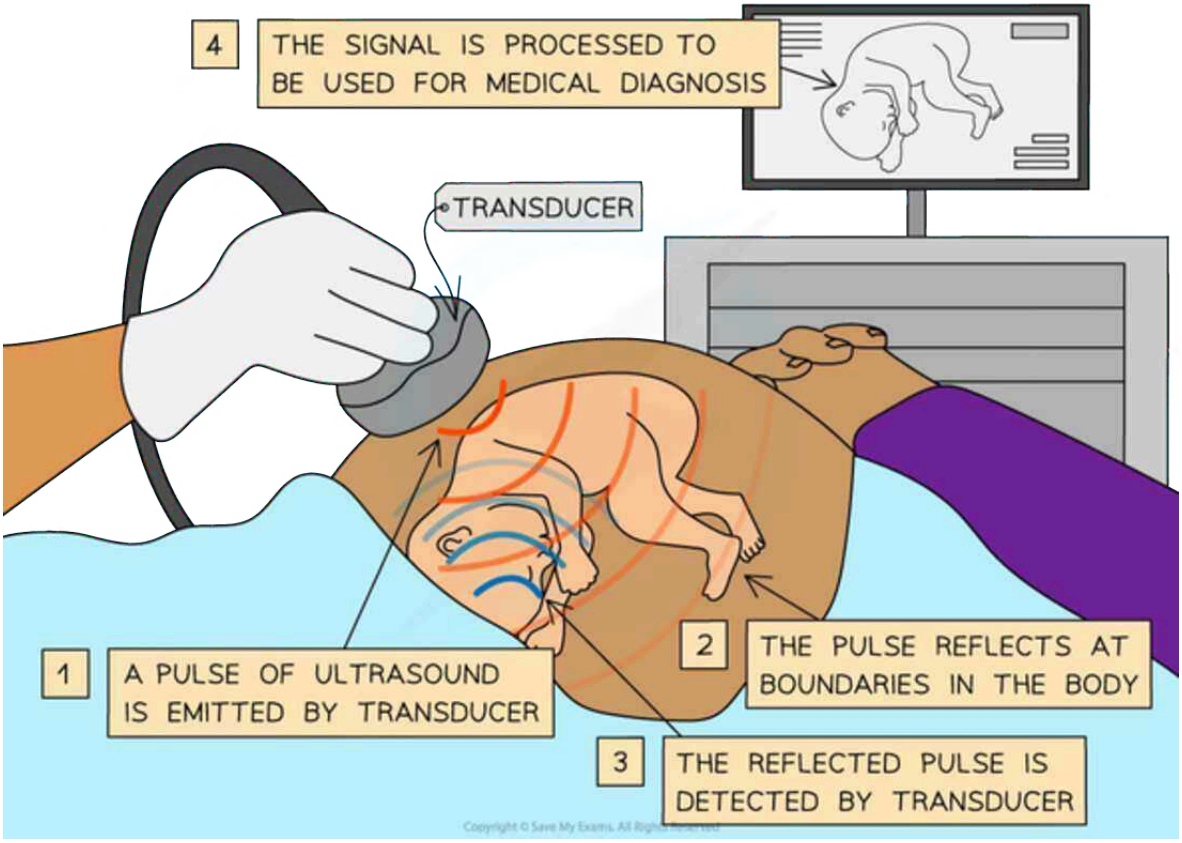
- In medicine, ultrasound can be used:
 - To construct images of a **foetus** in the womb
 - To generate 2D images of **organs** and other internal structures (as long as they are **not** surrounded by bone)
 - As a medical **treatment** such as removing kidney stones
- An ultrasound detector is made up of a **transducer** that produces and detects a beam of ultrasound waves into the body
- The ultrasound waves are reflected back to the transducer by **boundaries** between tissues in the path of the beam
 - For example, the boundary between fluid and soft tissue or tissue and bone
- When these echoes hit the transducer, they generate electrical signals that are sent to the ultrasound scanner
- Using the speed of sound and the time of each echo's return, the detector calculates the distance from the transducer to the tissue boundary
- By taking a series of ultrasound measurements, sweeping across an area, the time measurements may be used to build up an **image**

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- Unlike many other medical imaging techniques, ultrasound is **non-invasive** and is believed to be **harmless**

Your notes

Foetal Imaging Using Ultrasound



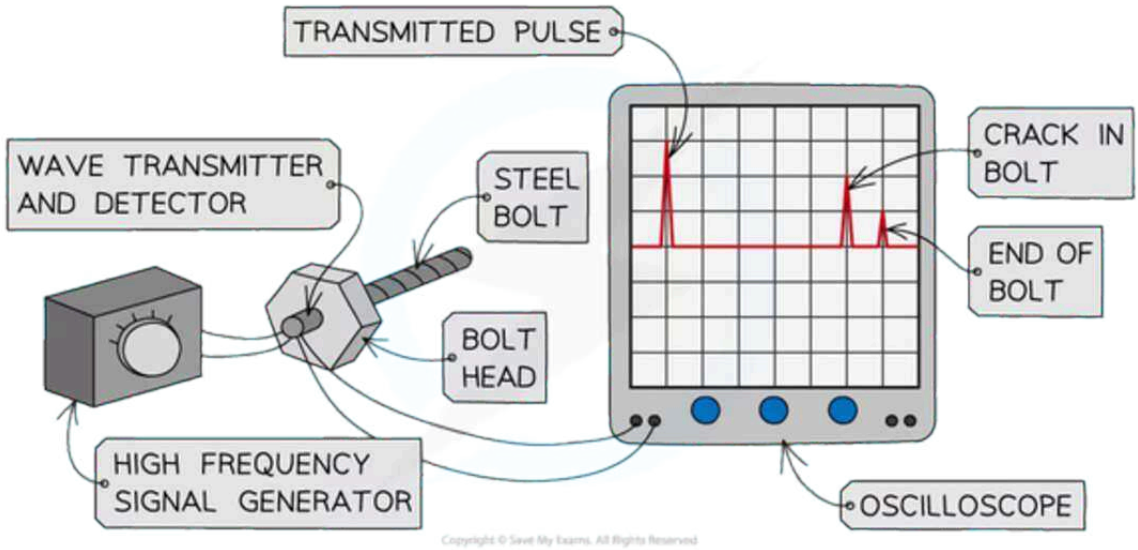
Ultrasound can be used to construct an image of a foetus in the womb

Ultrasound in Industry

- In industry, ultrasound can be used to:
 - Check for cracks inside metal objects
 - Generate images beneath surfaces
- A crack in a metal block will cause some waves to reflect earlier than the rest, so will show up as pulses on an oscilloscope trace
 - Each pulse represents each time the wave crosses a boundary
- The speed of the waves is constant, so measuring the time between emission and detection can allow the distance from the source to be calculated

Cracked Surface Detection Using Ultrasound

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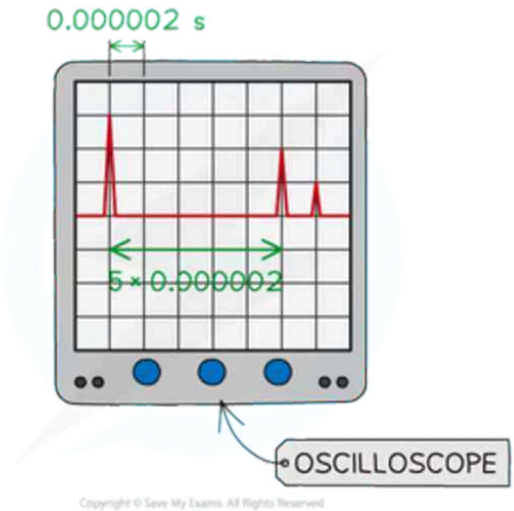


Ultrasound is partially reflected at boundaries, so in a bolt with no internal cracks, there should only be two pulses (at the start and end of the bolt)

Your notes

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Worked example



In the diagram above, a very high-frequency sound wave is used to check for internal cracks in a large steel bolt. The oscilloscope trace shows that the bolt does have an internal crack. Each division on the oscilloscope represents a time of 0.000002 s. The speed of sound through steel is 6000 m/s.

Calculate the distance, in cm, from the head of the bolt to the internal crack.

Answer:

Step 1: List the known quantities

- Speed of ultrasound, $v = 6000$ m/s
- Time taken, $t = 5 \times 0.000002 = 0.00001$ s

Step 2: Write down the equation relating speed, distance and time

$$\text{distance}, d = v \times t$$

Step 3: Calculate the distance

$$d = 6000 \times 0.00001 = 0.06 \text{ m}$$

Step 4: Convert the distance to cm

$$d = 6 \text{ cm}$$

Your notes

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Cambridge O Level Physics

Your notes

4.1 Simple Magnetism & Magnetic Fields

Contents

- Magnetism
- Magnets
- Magnetic Fields
- Plotting Magnetic Fields

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Magnetism

Your notes

Magnetism

Properties of Magnets

- The ends of a magnet are called **poles**
- Magnets have two poles: a **north** and a **south**

Poles of a Magnet



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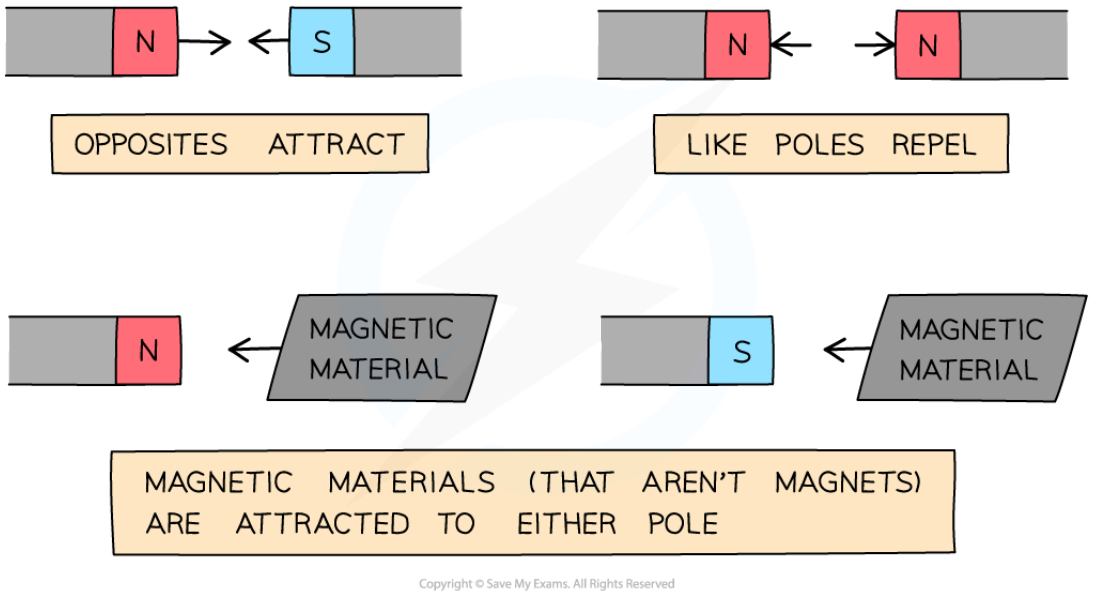
A magnet has a north and a south pole

- Magnets are objects which experience attraction and repulsion
 - **Like poles repel** (push each other apart)
 - For example a north pole will repel a north pole and a south pole will repel a south pole
 - **Unlike poles attract** (move towards each other)
 - For example a north pole will be attracted to a south pole

- When two magnets are held close together, there will be a force between the magnets:

Forces Between Magnets

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Opposite poles attract; like poles repel

- **Magnetic** materials:
 - Experience a **force** when placed in a magnetic field
 - Are attracted to a magnet when **unmagnetised**
 - Can be **magnetised** to form a magnet
- Only a **magnet** can **repel** another magnet (This can be a useful test for a magnet)
- **Non-magnetic materials** do **not** experience a force when placed in a magnetic field

Your notes

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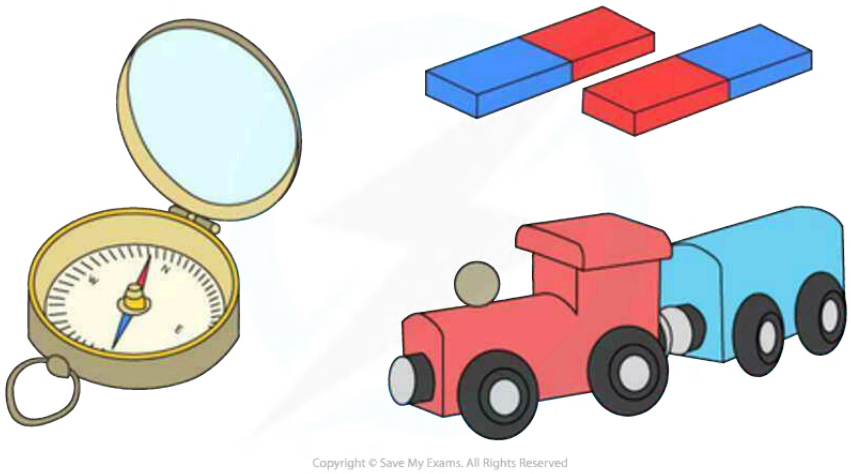
Uses of Magnets

Uses of Permanent Magnets

Your notes

- Permanent magnets are usually (but not always) made from steel
 - They tend to stay magnetised

Examples of Uses of Permanent Magnets



Permanent magnets are often in found in compasses and children's toys

- Permanent magnets have many uses including
 - **Compasses:** for thousands of years humans have used compasses for navigation, since the needle always points north
 - **School lab experiments:** the magnets used in school science demonstrations are permanent magnets
 - **Toys:** toy trains and trucks often have magnets which attach the carriages or trailers to the engine or cab
 - **Fridge magnets:** these are made either of flexible magnetic material or by sticking a magnet to the back of something

Uses of Electromagnets

- Electromagnets use electricity to create a magnet from a current-carrying wire
 - They have the advantage that they can be magnetised and demagnetised, literally at the flick of a switch

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- They can be switched on and off
- Soft iron is the metal normally used for this
 - It can easily become a temporary magnet

Your notes

Uses of Temporary Magnets



Temporary magnets like electromagnets are used in industry and medicine

- Electromagnets have many uses including
 - **MRI scanners:** in hospitals, an MRI scanner is a large, cylindrical machine using powerful electromagnets to produce diagnostic images of the organs of the body
 - **Speakers and earphones:** the loudspeakers, microphones and earphones used in phones and laptops use electromagnets to sense or send soundwaves
 - **Recycling:** because steel is a magnetic material it can be easily separated from other metals and materials using electromagnets. Once recovered the steel is re-used and recycled, reducing mining for iron ore and processing ore into steel
 - **Mag-Lev Trains:** the ability of Mag-Lev trains to hover above the rails is due to them being repelled by large electromagnets on the train and track. This reduces friction and allows speeds of nearly 400 miles per hour

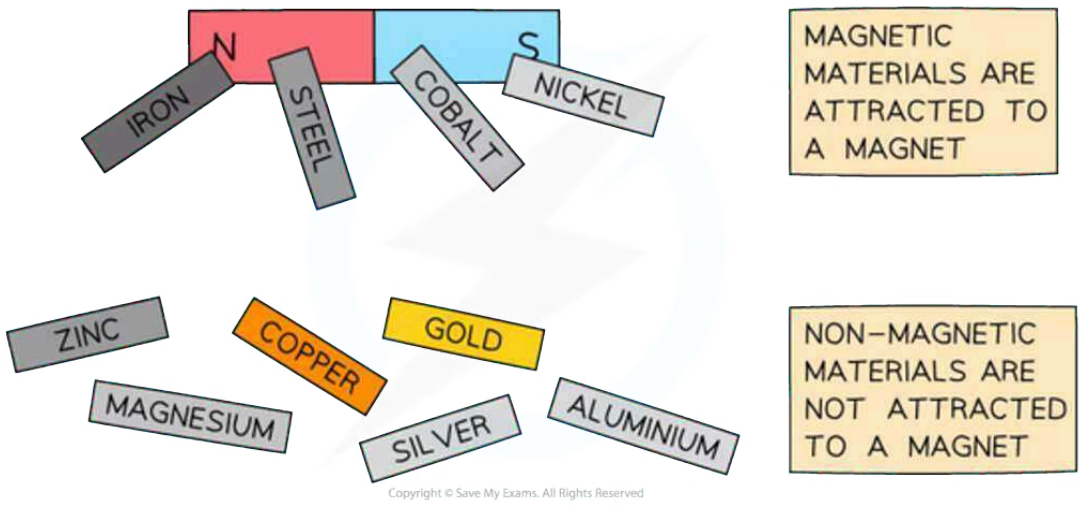
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Magnets

Your notes

Magnets

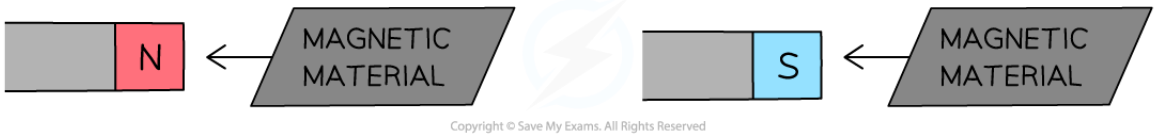
Magnetic and Non-magnetic Materials



Magnetic materials are attracted to a magnet; non-magnetic materials are not

- Very few metals in the Periodic Table are magnetic. These include:
 - Iron
 - Cobalt
 - Nickel
- Steel is an alloy which contains iron, so it is also magnetic
- Magnetic materials (which are not magnets) will always be **attracted** to the magnet, regardless of which pole is held close to it

Magnetism in Magnetic Materials



Magnetic materials are attracted to both poles of a magnet

- To test whether a material is a magnet it should be brought close to a known magnet
 - If it can be **repelled** by the known magnet then the material itself is a magnet

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- If it can only be **attracted** and **not repelled** then it is a magnetic material


Your notes

Types of Magnets

- There are two types of magnets
 - Permanent magnets
 - Induced magnets

Permanent Magnets

- Permanent magnets are made out of permanent magnetic materials, for example steel
- A permanent magnet will **produce its own magnetic field**
 - It will not lose its magnetism

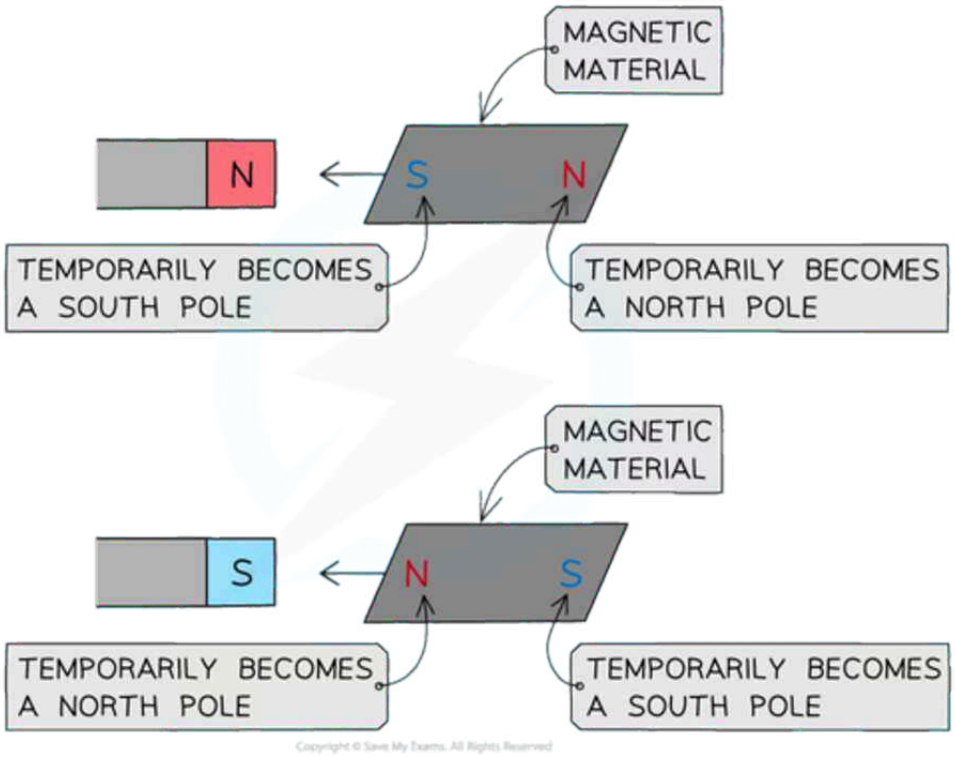
Temporary (Induced) Magnets

- When a magnetic material is placed in a magnetic field, the material can **temporarily** be turned into a magnet
 - This is called **induced magnetism**
 - Some objects such as paperclips or needles (which are made from steel) can be magnetised and will remain magnetic for a while
 - Other objects, such as electromagnets or transformers (which are made from iron) will be demagnetised as soon as the cause of the induced magnetism is removed
- When magnetism is induced on a material:
 - One end of the material will become a north pole
 - The other end will become a south pole
- Magnetic materials will always be **attracted** to a permanent magnet
- This means that the end of the material closest to the magnet will have the **opposite** pole to magnets pole closest to the material

Magnetic Induction in Magnetic Materials

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Your notes



Magnetic poles are induced in a magnetic material; the induced pole is always the opposite pole to the pole of the permanent magnet

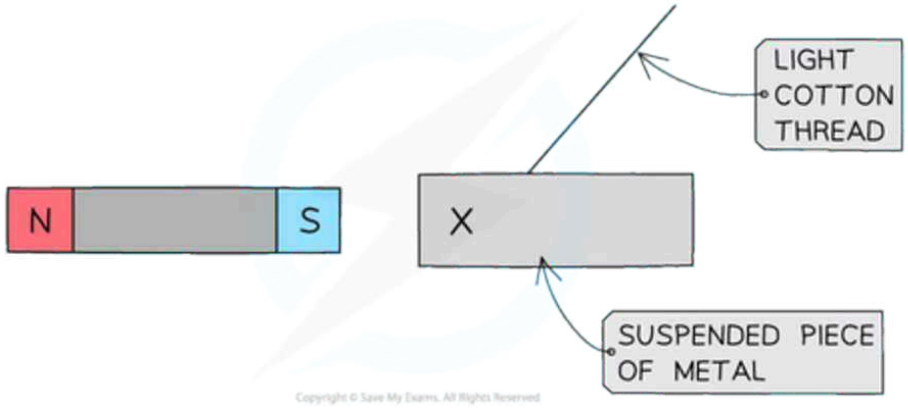
- When the magnetic material is removed from the magnetic field it will lose most/all of its magnetism quickly

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Your notes

Worked example

The diagram below shows a magnet held close to a piece of metal that is suspended by a light cotton thread. The piece of metal is attracted towards the magnet.



Which of the following rows in the table gives the correct type of pole at X and the correct material of the suspended piece of metal?

	Type of pole at X	Material of suspended piece of metal
A	North	Nickel
B	South	Nickel
C	North	Aluminium
D	South	Aluminium

Answer: A

- X must be a north pole
 - The piece of metal is being attracted towards the magnet
 - The law of magnetism states that opposite poles attract
- The material of the suspended piece of metal is nickel
 - Nickel is a magnetic material (It will experience a force when it is placed in a magnetic field, in this case it is attracted towards the magnet)
- **B** is incorrect because X cannot also be a south pole (and hence is a north pole)
 - If the pole at X was a south pole then the piece of metal would be repelled from the magnet because the law of magnetism states that like poles repel
- **C** and **D** are incorrect because aluminium is not a magnetic material
 - A non-magnetic material would be unaffected by the magnetic field produced by the magnet.

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Your notes

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Magnetic Fields

Your notes

Magnetic Fields

- All magnets are surrounded by a **magnetic field**
- A magnetic field is defined as:

> **The region around a magnet where a force acts on another magnet or on a magnetic material (such as iron, steel, cobalt and nickel)**

- Two bar magnets can be used to produce a uniform magnetic field
- Point opposite poles (north and south) of the two magnets a few centimetres apart
- A **uniform** magnetic field will be produced in the **gaps** between **opposite poles**
 - Note: Outside that gap, the field will **not** be uniform

Magnetic Field Between Two Poles



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A uniform field is created when two opposite poles are held close together. Magnetic fields are always directed from North to South

- A uniform magnetic field is one that has the **same strength and direction at all points**
 - To show that the magnetic field has the same strength at all points there must be **equal spacing** between all magnetic field lines
 - To show that the magnetic field is acting in the same direction at all points there must be an arrow on each magnetic field line going from the **north** pole to the **south** pole
- The magnetic field lines are the **same distance apart** between the gaps of the poles to indicate that the field strength is the same at every point between the poles
- This field can be determined by using plotting compasses that will point from **north** to **south** or by using iron filings

Magnetic Field Lines

- Magnetic field lines are used to represent the **strength** and **direction** of a magnetic field
- The direction of the magnetic field is shown using **arrows**

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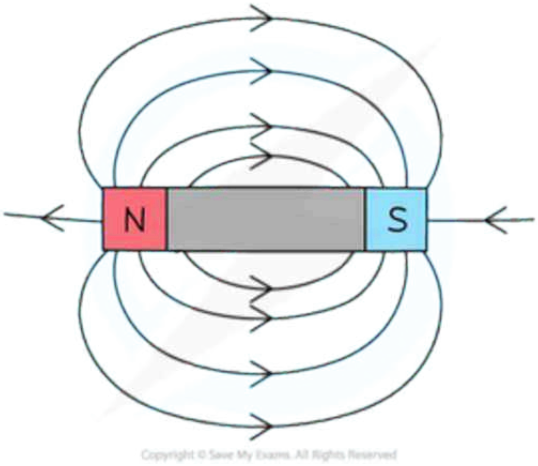
- There are some rules which must be followed when drawing magnetic field lines. Magnetic field lines:
 - Always go **from north to south** (indicated by an arrow midway along the line)
 - Must **never touch or cross** other field lines

Your notes

Magnetic Field Around a Bar Magnet

- The magnetic field is **strongest at the poles**
 - This is where the magnetic field lines are **closest** together
- The magnetic field becomes **weaker as the distance from the magnet increases**
- This is because the magnetic field lines are getting **further apart**

Magnetic Field Around a Bar Magnet



The magnetic field around a bar magnet loops outward from the north pole to the south pole

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Magnetic Field Strength

Your notes

- The **strength** of the magnetic field is shown by the **spacing** of the magnetic field lines
 - If the magnetic field lines are **close together** then the magnetic field will be **strong**
 - If the magnetic field lines are **far apart** then the magnetic field will be **weak**

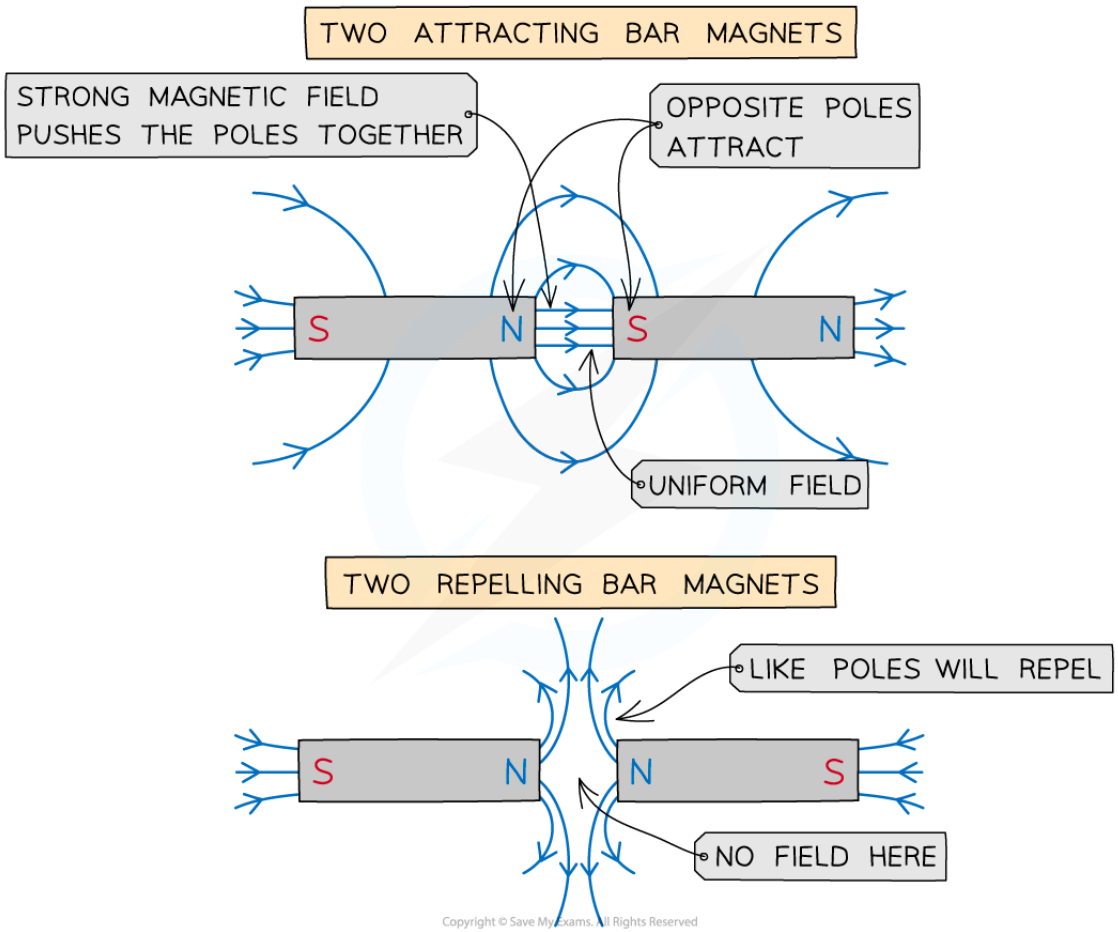
- Magnetic forces are due to interactions between magnetic fields
 - Two bar magnets can repel or attract

- The field lines will look slightly different for each:

Magnetic Fields Showing Attraction and Repulsion

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Your notes



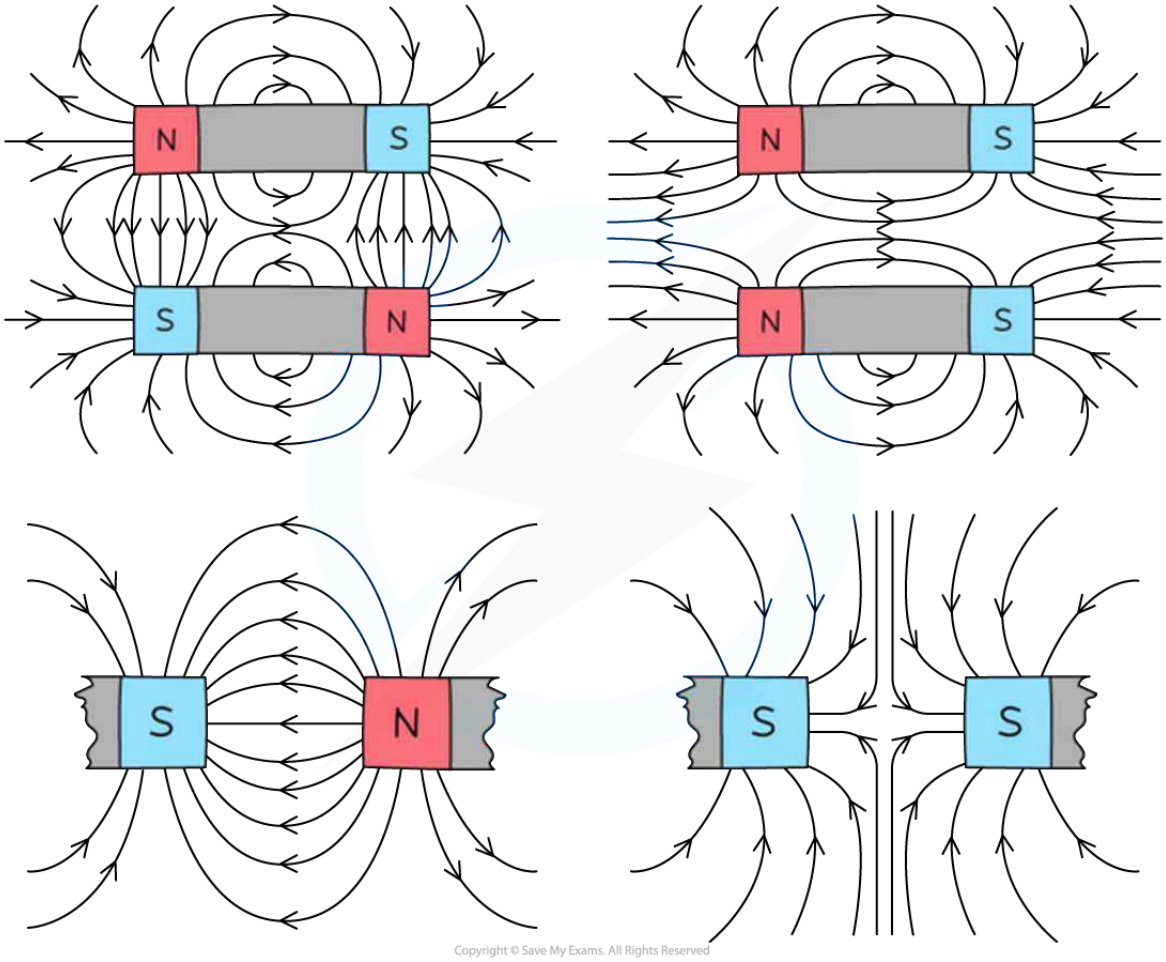
Magnetic field lines for attracting and repelling bar magnets

- Therefore, the magnetic field lines around different configurations of two bar magnets would look like:

Magnetic Field Patterns for Different Orientations of Bar Magnets

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Your notes



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Magnetic field lines between two bar magnets

Exam Tip

If you are asked to draw the magnetic field around a bar magnet remember to indicate both the **direction** of the magnetic field and the **strength** of the magnetic field.You can do this by:

- Adding arrows pointing away from the north pole and towards the south pole
- Making sure the magnetic field lines are further apart as the distance from the magnet increases

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Plotting Magnetic Fields

Your notes

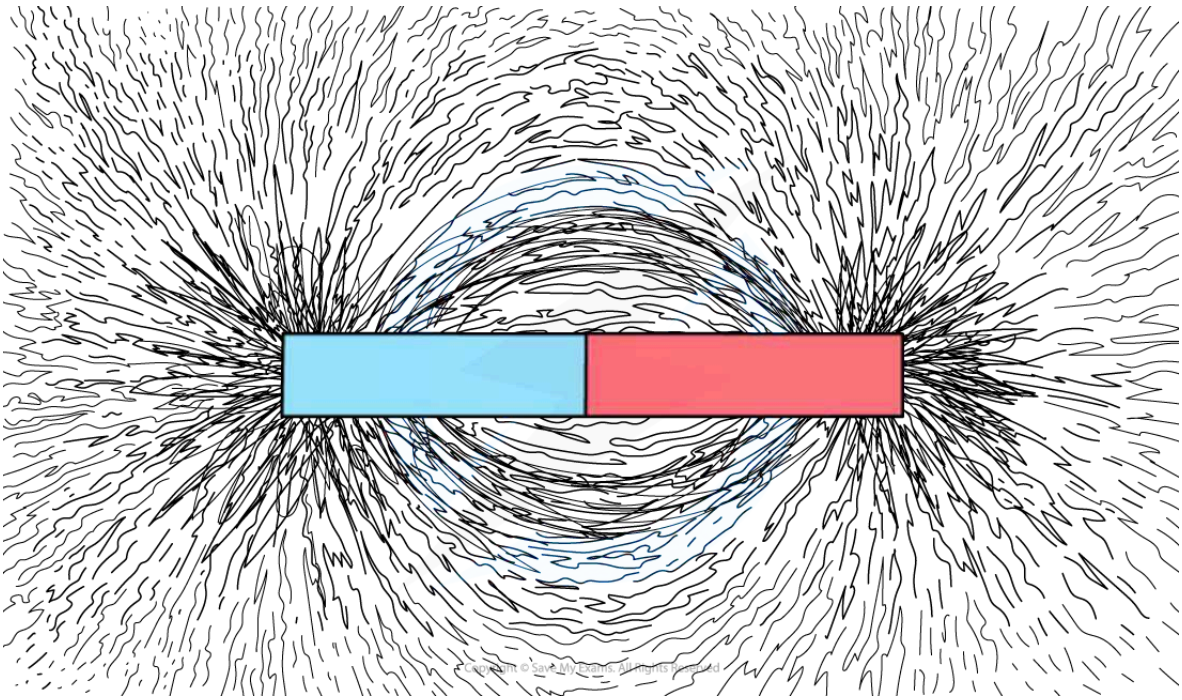
Plotting Magnetic Field Lines

- In your examination you might be asked to describe a method of plotting the magnetic field around a bar magnet
- There are two principle ways of doing this:

Using Iron Filings

- Place a piece of paper on top of the magnet
- Gently sprinkle iron filings on top of the paper
- Now carefully tap the paper to allow the iron filings to settle on the field lines

Magnetic Field Shown Using Iron Filings


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Iron filings can be used to plot a magnetic field

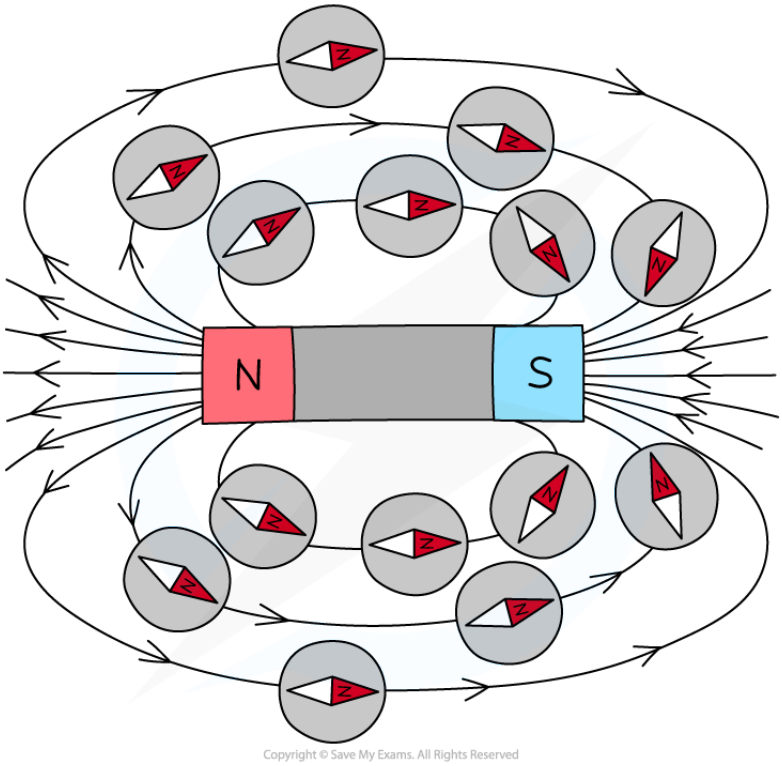
- Place the magnet on top of a piece of paper
- Draw a dot at one end of the magnet (near its corner)
- Place a plotting compass next to the dot, so that one end of the needle of the compass points towards the dot
- Use a pencil to draw a new dot at the other side of the compass needle

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- Now move the compass so that it points towards the new dot, and repeat the above process
- Keep repeating until you have a chain of dots going from one end of the magnet to the other. Then remove the compass, and link the dots using a smooth curve – the magnetic field line
- The direction of the field line is the same as the direction of the plotting compass
- You can now repeat the whole process several times to create several other magnetic field lines

Your notes

Magnetic Field Shown Using Plotting Compasses



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Compasses can be used to plot the magnetic field around a bar magnet

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Cambridge O Level Physics

Your notes

4.2 Electrical Quantities

Contents

- Electrical Charge
- Demonstrating Electric Charges
- Electric Fields
- Investigating Conductors & Insulators
- Electrical Current
- Electromotive Force & Potential Difference
- Resistance
- Resistance of a Wire

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Electrical Charge

Your notes

Positive & Negative Charges

- Objects can be given one of two types of electric charge:
 - **Positive**
 - **Negative**
- When two charged objects are brought close together, there will be a force between those objects

Forces Acting on Point Charges



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Like charges repel; opposite charges attract

- Remember:
 - **Opposite charges attract**
 - **Like charges repel**
- Electric charge is measured in units called **coulombs (C)**

Exam Tip

Whilst electrostatic forces share many similarities with magnetic forces, they are different phenomena **– take care not to confuse the two!**

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Demonstrating Electric Charges

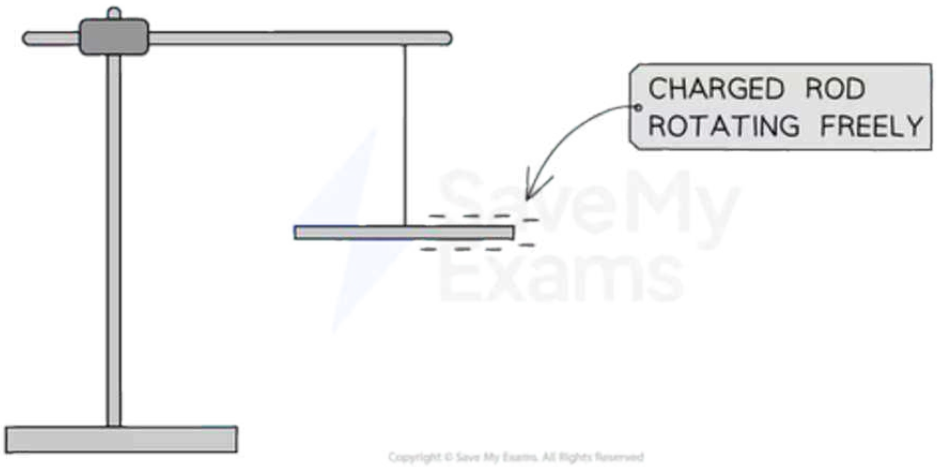
Your notes

Demonstrating Electrostatic Charges

- Electrostatic repulsion is caused by the force between charges
 - When these charges are the same as each other, they repel (push apart)
- In simple experiments showing the production of electrostatic charges by friction, insulating solids such as plastics are given a charge
 - This is done using friction to transfer electrons from the surface
- By removing electrons, which have negative charge, the insulator is left with a positive charge

Method

Demonstrating Electrostatic Charge Using the Cradle Method



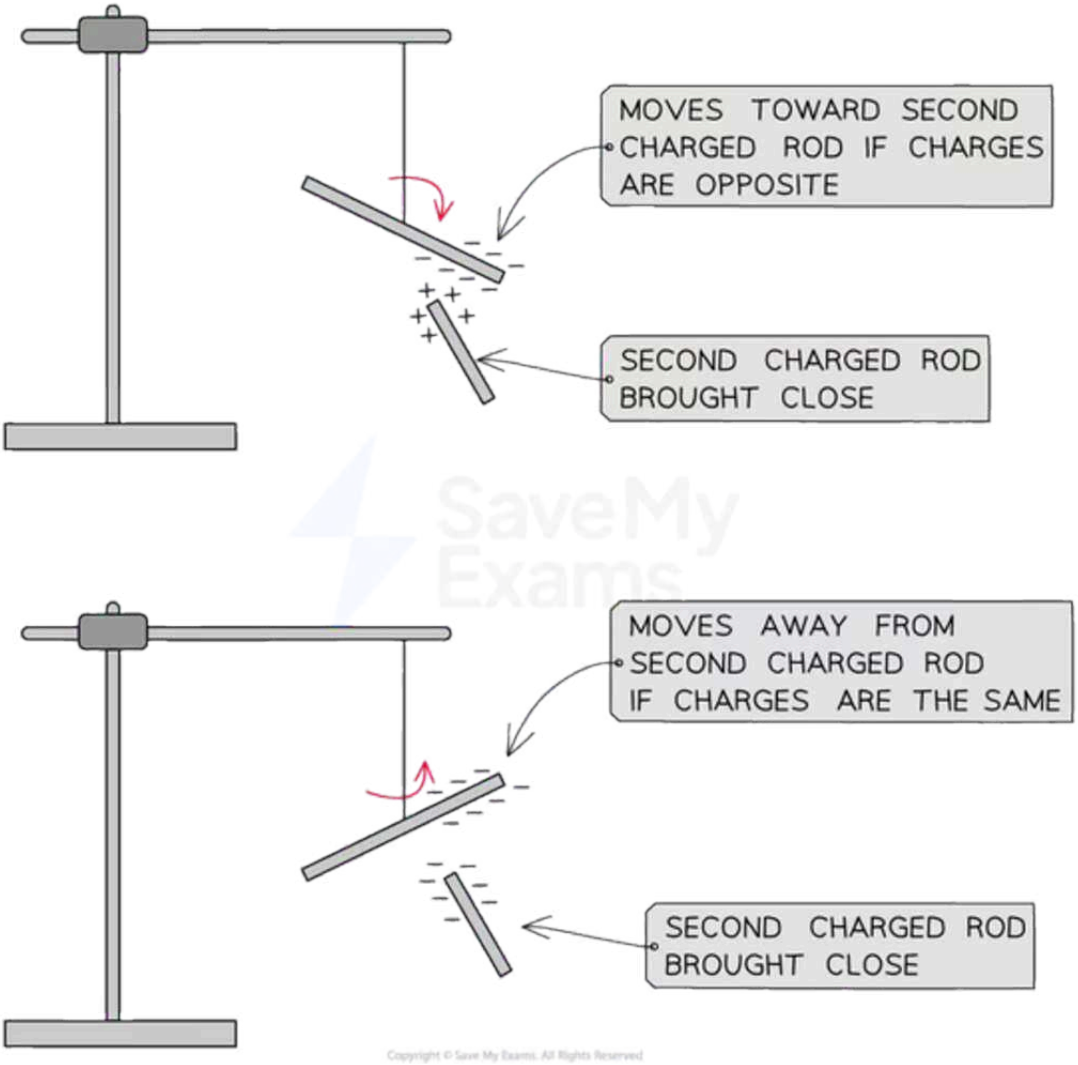
A charged rod is held by a length of thread from a clamp stand so that it can rotate freely

- Suspend one of the insulating materials using a cradle and a length of string so that the material can rotate freely
- Rub one end of the material using a cloth (in order to give it a charge)
- Now take a second piece of insulating material and charge that by rubbing with a cloth
- Hold the charged end of the second piece close to the charged end of the first piece:
 - If the first piece rotates away (is repelled) from the second piece then the materials have the same charge
 - If the first piece moved towards (is attracted to) the second piece then they have opposite charges

Attraction & Repulsion of Charged Rods

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Your notes



If the charged rods have opposite charges, the freely rotating rod will turn toward the second rod. If the charged rods have like charges, the freely rotating rod will turn away from the second rod

Exam Tip

Experimental demonstrations, such as the one above, are different from experiments in which you have to take measurements. In the case of this demonstration your results are your **observations**.

When describing a demonstration you should **state a conclusion** – in other words, explain what you expect to happen and what it means.

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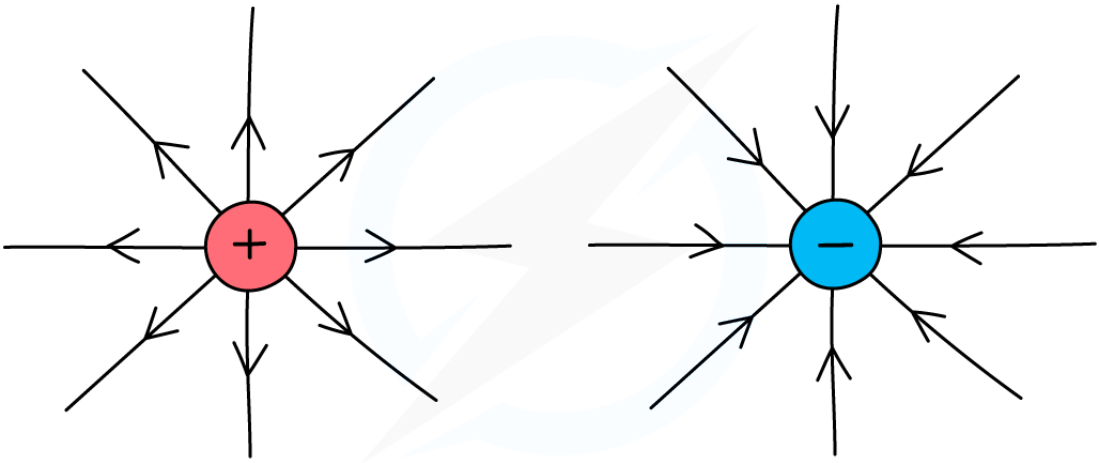
Electric Fields

Your notes

Electric Fields

- A charged object creates an **electric field** around itself
 - This is similar to the way in which magnets create magnetic fields
- This can be shown by electric field lines
 - Fields lines always point **away from positive** charges and **towards negative** charges

Direction of Field Lines for Point Charges



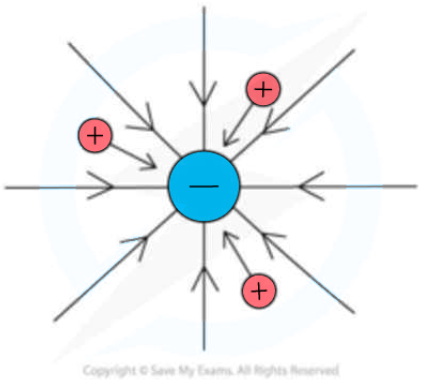
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Electric fields are always directed away from positive charges and towards negative charges

- The direction of the field lines in an electric field is described as:

The direction of the force on a positive charge at that point

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Field lines show the direction that a positive charge would experience if it was at that point

- Although the definition of the force direction refers to a positive charge, in demonstrations it is always electrons (negative charges) which are free to move according to that force
- The strength of an electric field depends on the distance from the object creating the field:
 - The field is **strongest close** to the charged object - this is shown by the field lines being **closer together**
 - The field becomes **weaker further away** from the charged object - this is shown by the field lines becoming **further apart**

Your notes

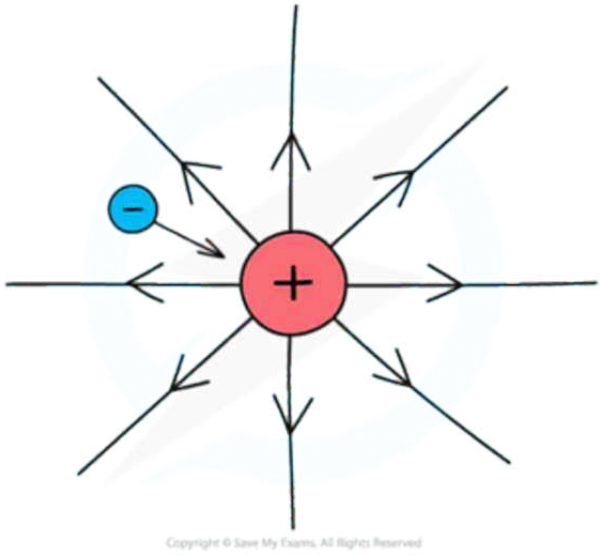
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Electric Field Patterns

Your notes

- Objects in an electric field will experience an electrostatic **force**
 - Since force is a vector, the direction of this force depends on whether the charges are the same or opposite
 - If the charges are the **same** (negative and negative or positive and positive), this force will be **repulsive** and the second charged object will move away from the charge creating the field
 - If the charges are the **opposite** (negative and positive), this force will be **attractive** and the second charged object will move **toward** the charge creating the field
 - The force is either **attractive** or **repulsive**

Force on a Negative Charge Placed in the Electric Field of a Positive Charge



Electric field lines show force direction and force strength

- The size of the force depends on the strength of the field at that point
- This means that the force becomes:
 - **Stronger** as the distance between the two charged objects **decreases**
 - **Weaker** as the distance between the two charged objects **increases**
- The relationship between the strength of the force and the distance applies to both the force of attraction and force of repulsion
 - Two negative charges brought close together will have a **stronger** repulsive force than if they were far apart

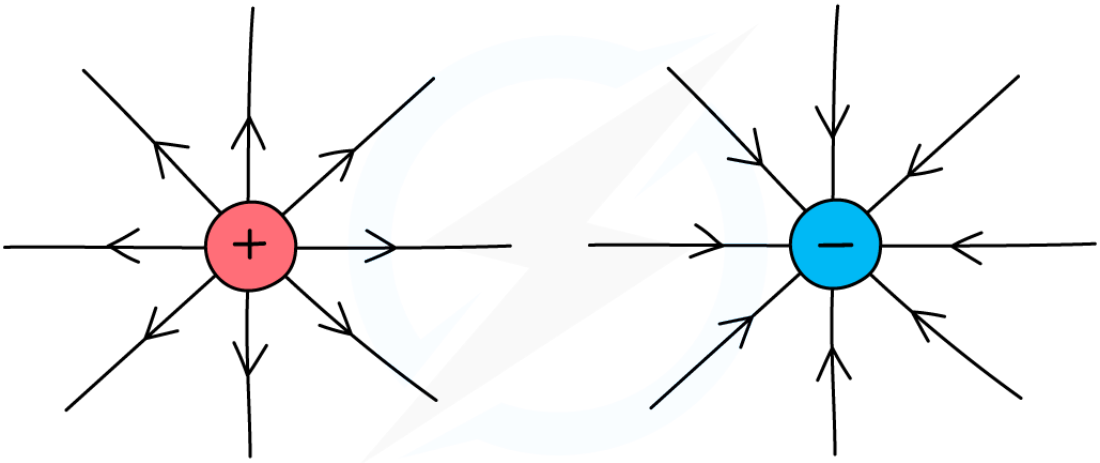
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Field Lines Around a Point Charge

Your notes

- The electric field is the region in which another charge will experience a force
- Fields lines always go away from positive charges and towards negative charges – they have the same direction as the direction of the force on a positively charged particle at a point in that field

Fields Lines For Point Charges



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Electric fields are always directed away from positive charges and towards negative charges

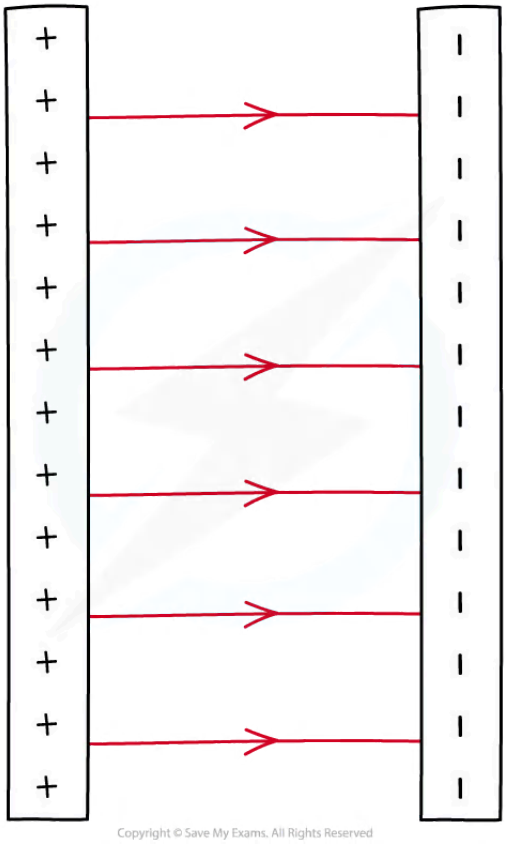
Field Lines Between Two Oppositely Charged Parallel Conducting Plates

- The electric field between two parallel plates is a **uniform electric field**
- The field lines are:
 - Directed from the **positive** to the **negative** plate
 - Parallel
 - Straight lines

Field Lines for Parallel Plates

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Your notes



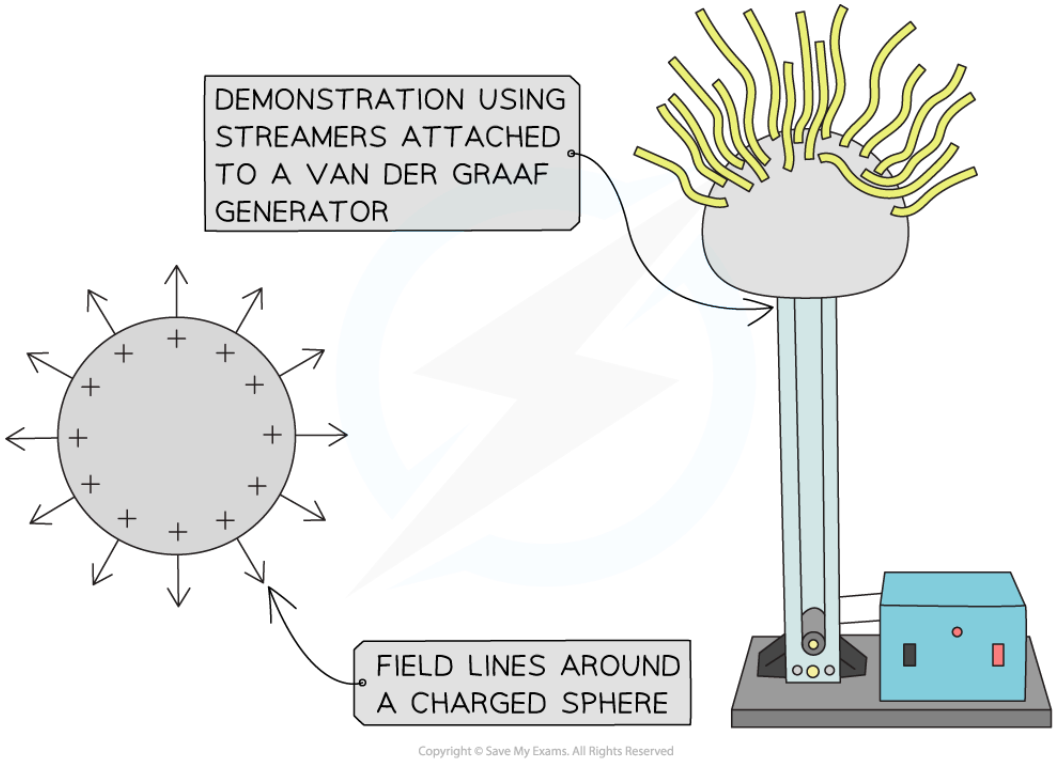
The electric field between two parallel plates

Field Lines Around a Charged Conducting Sphere

- The field lines around a charge conducting sphere are symmetrical, as with a point charge
 - This is because the charges on the surface of the sphere will be evenly distributed
 - The charges are the same, so they repel
 - The surface is conducting, allowing them to move

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Your notes



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- This field line pattern can be demonstrated using a Van der Graaff Generator
- One method using streamers is shown
- Other methods often demonstrated in schools include
 - Small pieces of paper
 - Polystyrene beads
 - Aluminium foil containers

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Investigating Conductors & Insulators

Your notes

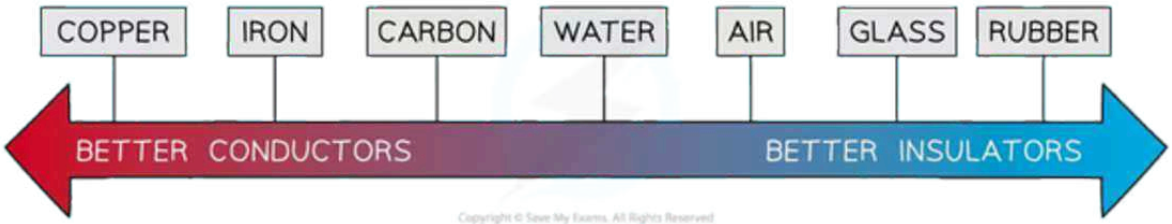
Conductors, Insulators & Electrons

- The key difference between conductors and insulators is that:
 - Conductors allow charge carriers to freely move
 - Insulators do not allow charge carriers to move
- The reasons for this are to do with their internal structure

Conductors

- A **conductor** is a material that allows **charge** (usually electrons) to flow through it easily
- Examples of conductors are:
 - Silver
 - Copper
 - Aluminium
 - Steel
- Conductors tend to be **metals**

Relative Conductivity of Different Materials

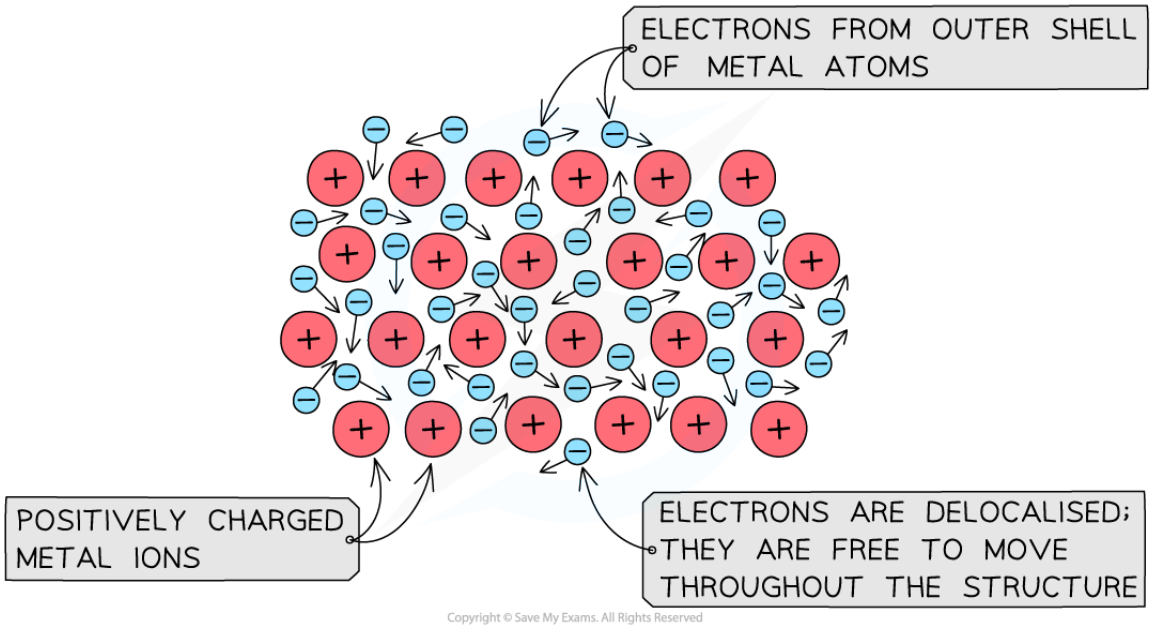


Different materials have different properties of conductivity

- On the atomic scale, conductors are made up of positively charged metal ions with their outermost electrons **delocalised**
 - This means the electrons are free to move
- Metals conduct electricity very well because:
 - Current is the rate of flow of charged particles
 - So, the more easily electrons are able to flow, the **better** the conductor

Metallic Bonding and Delocalised Electrons

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The lattice structure of a conductor with positive metal ions and delocalised electrons

Insulators

- An **insulator** is a material that has **no free charges,** hence does **not** allow the flow of charge through them very easily
- Examples of insulators are:
 - Rubber
 - Plastic
 - Glass
 - Wood

- Some non-metals, such as wood, allow some charge to pass through them
- Although they are not very good at conducting, they do conduct a little in the form of **static** electricity
 - For example, two insulators can build up charge on their surfaces. If those surfaces touch, this would allow that charge to be conducted away

Your notes

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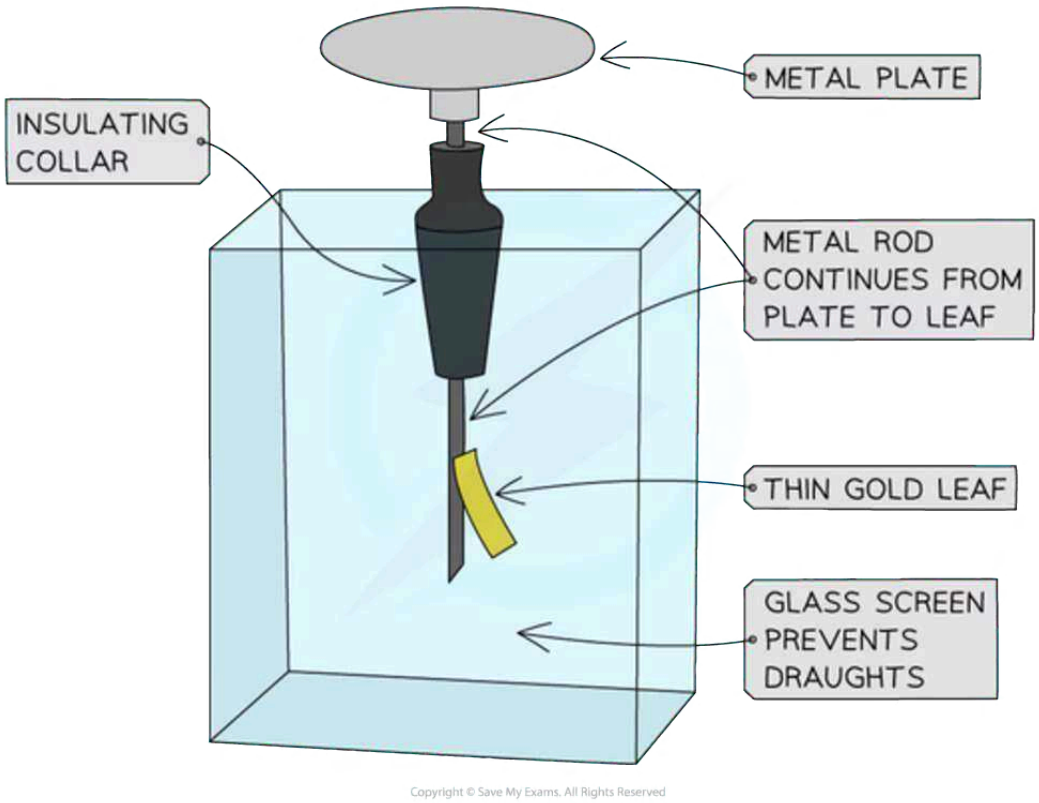
Investigating Electrical Conductors & Insulators

The Gold-leaf Electroscope (GLE)

Your notes

- To distinguish between conductors and insulators a **Gold-leaf electroscope (GLE)** can be used

Gold-Leaf Electroscope



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The gold-leaf electroscope is a device used to demonstrate charge

- The GLE consists of
 - A **metal plate** attached to one end of a **metal rod**
 - At the other end of the **rod** a very **thin leaf of gold foil** is attached
 - The rod is held by an **insulating collar** inside a box with **glass sides**, allowing the gold leaf to both be seen and protected from draughts
- When the GLE is charged, the plate, rod and gold leaf have the same charge (either positive or negative)
 - Since the rod and leaf have the **same charge**, they **repel**, and the leaf sticks out to the side
 - When the rod and leaf are discharged (are **neutral**) the leaf **hangs down**

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To Test Electrical Conductors and insulators

- Charge the plate of the GLE so that the gold leaf stands clear of the rod
- Carefully touch the plate of the GLE with the items being tested, for example:
 - Metals, such as: wire, paperclip, scissor blades
 - Non-metals, such as: paper, fingers, glass, graphite
 - Plastics, such as: plastic ruler, the handles of the scissors, finger in a plastic sandwich bag
 - Comparisons, such as: wet cloth, dry cloth; finger and finger in a plastic sandwich bag
- Record the observations each time
 - **Leaf falls**: material is a **good** conductor
 - Leaf **remains** in place: object is a **poor** conductor (good insulator)
 - Leaf **falls slowly**: material is a **poor** conductor


Your notes

Alternative method

- An **electronic charge detector** can be used in place of the Gold-leaf Electroscope

Expected Results

- Overall, **metals** are very good **conductors** whilst **non-metals** tend to be good **insulators**

Conductors & Insulators Summary Table

Conductors	Insulators
Metals	Plastics
Graphite	Glass
	Most other non-metals

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Electrical Current


Your notes

Current

- **The current is the amount of charge passing a point in a circuit every second**

(It is helpful to think of current as the **charge per second**)

- Charge, current and time are related by the following equation:

$$\text{charge} = \text{current} \times \text{time}$$

$$Q = It$$

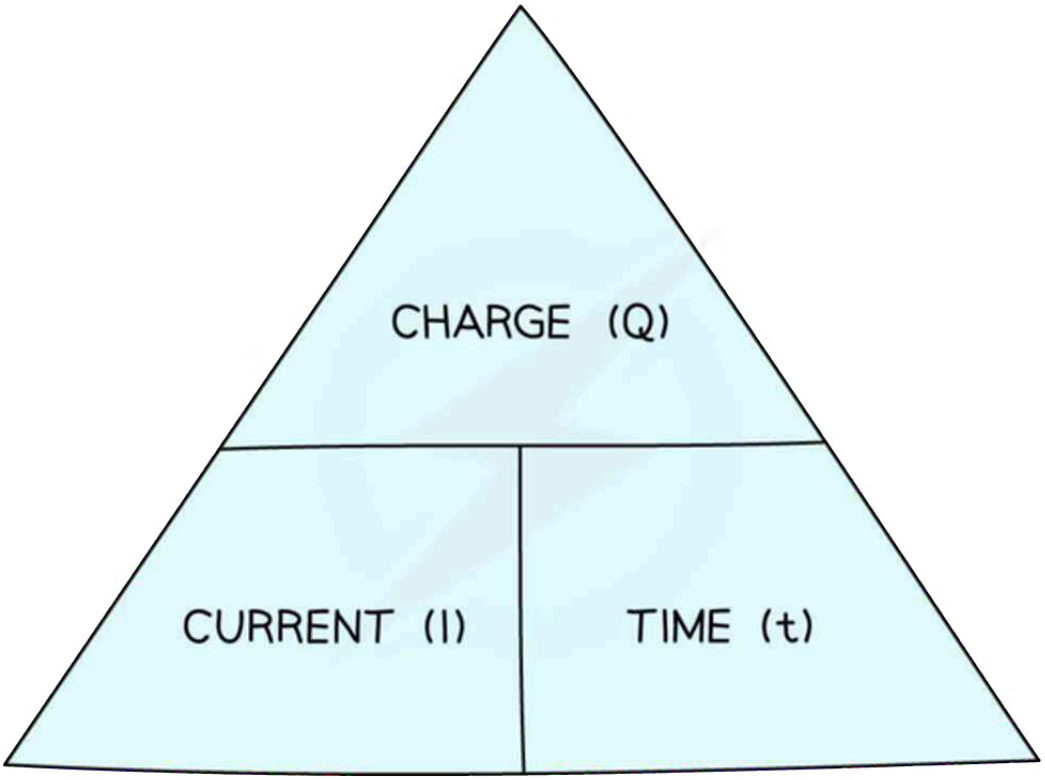
- Where:
 - **Q = charge (measured in coulombs, C)**
 - ***I* = current (measured in amps, A)**

- You can rearrange this equation with the help of the formula triangle:

Equation Triangle for Current Equation

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Your notes



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Use the formula triangle to help you rearrange the equation until you feel comfortable doing it on your own

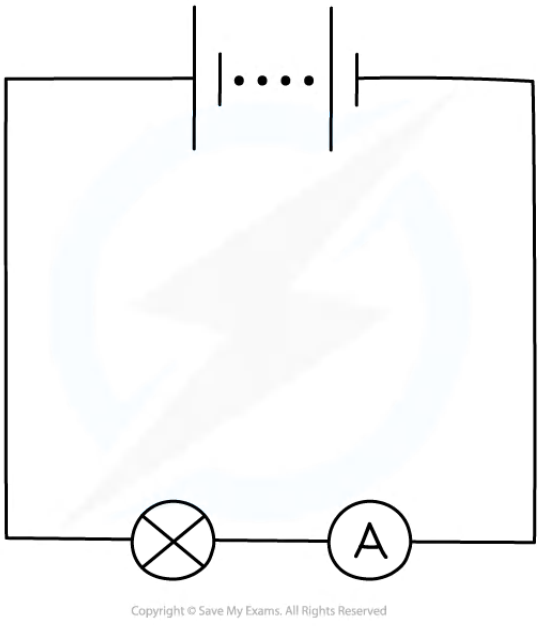
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Measuring Current

Your notes

- Current is measured using an ammeter
- Ammeters should always be connected in series with the part of the circuit you wish to measure the current through
 - Ammeters measure the amount of charge passing through them per unit time, so the ammeter has to be in series so that all the charge flows through it

Simple Circuit Diagram



An ammeter can be used to measure the current around a circuit

Digital or Analogue?

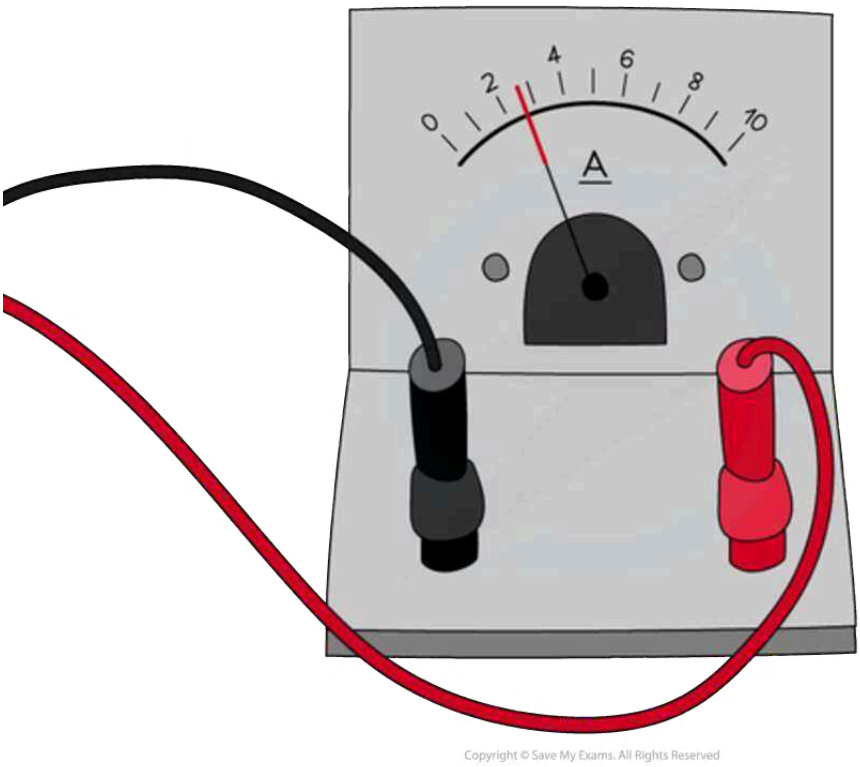
- Ammeters can be either
 - Digital (with an electronic read out)
 - Analogue (with a needle and scale)

Analogue Ammeters

- Typical ranges are 0.1–1.0 A and 1.0–5.0 A for analogue ammeters
 - Always double check exactly where the marker is before an experiment, if not at zero, you will need to subtract this from all your measurements. They should be checked for zero errors before using

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- They are also subject to parallax error
 - Always read the meter from a position directly perpendicular to the scale



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Digital Ammeters

- Digital ammeters can measure very small currents, in mA or μA
- Digital displays show the measured values as digits and are more accurate than analogue displays
- They're easy to use because they give a specific value and are capable of displaying more precise values
 - However digital displays may 'flicker' back and forth between values and a judgement must be made as to which to write down
- Digital ammeters should be checked for zero error
 - Make sure the reading is zero before starting an experiment, or subtract the "zero" value from the end results

Your notes

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Digital meter

Your notes

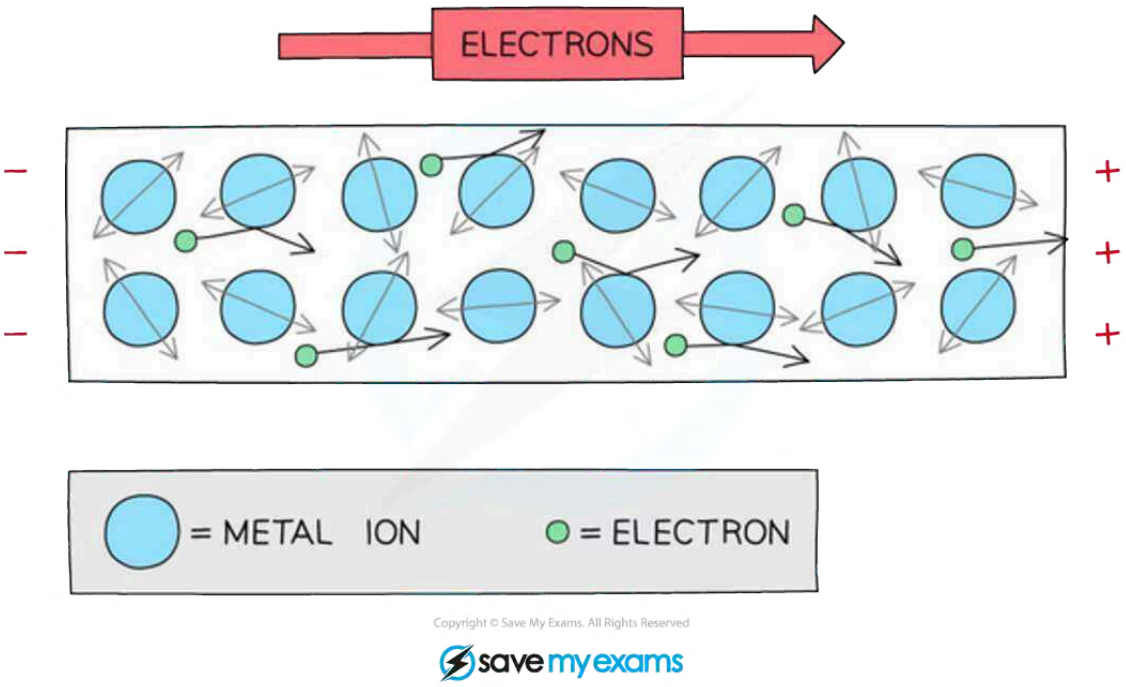
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Electrical Conduction in Metals

- In a metal, current is caused by a flow of electrons

Your notes

Conduction in Metals



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In metals, the current is caused by a flow of free (delocalised) electrons

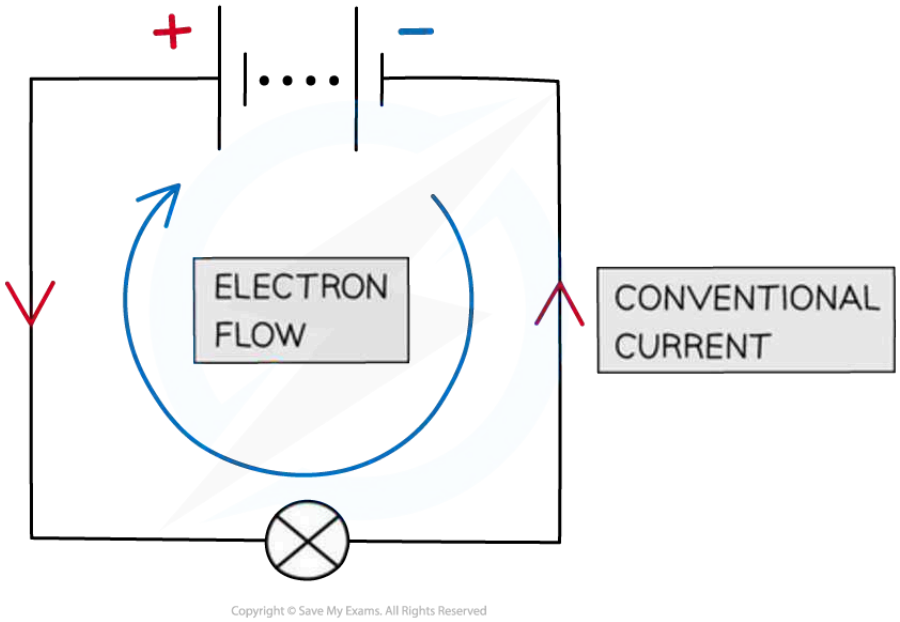
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Conventional Current

Your notes

- **Electrons are negatively charged**
- This means that the **electrons flow from negative to positive**
- **Conventional current**, however, is still defined as going from **positive to negative**

Conventional Current Versus Electron Current



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By definition, conventional current always goes from positive to negative (even though electrons go the other way)

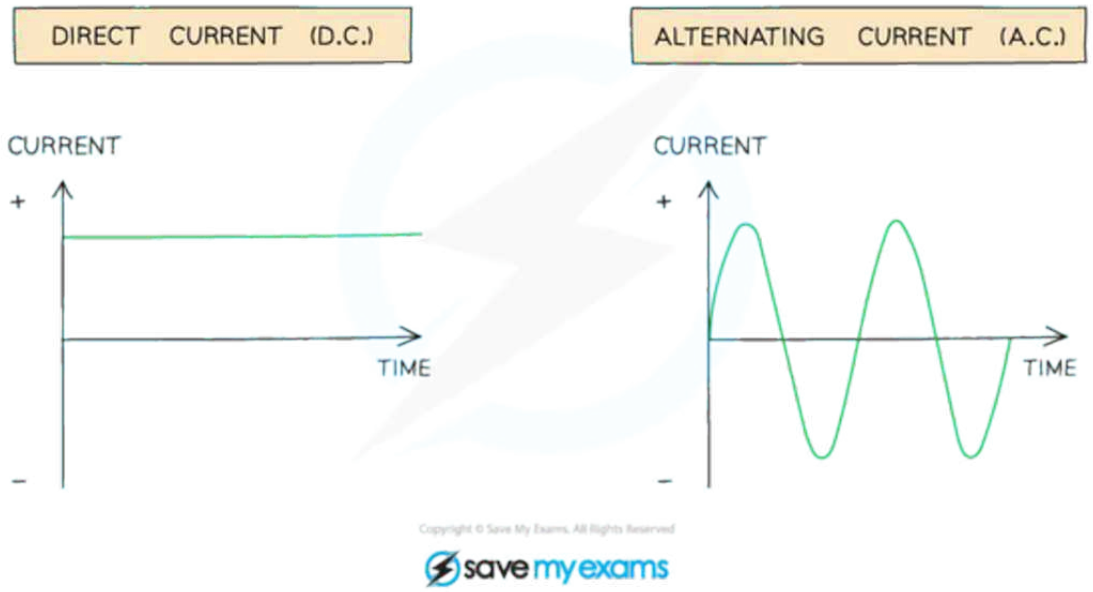
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Direct & Alternating Current

Your notes

- **An alternating current (a.c.) is one that continuously changes its direction**, going back and forth around a circuit
- **A direct current (d.c.) is one that is steady, constantly going the same way around a circuit**, from positive to negative

A.C. and D.C. Current Graphs



Two graphs showing the variation of current with time for alternating current and direct current

- Electric cells (batteries) produce direct current (d.c.)
- Mains electricity is an alternating current

Exam Tip

If asked to explain the difference between alternating and direct current, sketch the graphs shown above: a well-sketched (and labelled) graph can earn you full marks.

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Electromotive Force & Potential Difference

Your notes

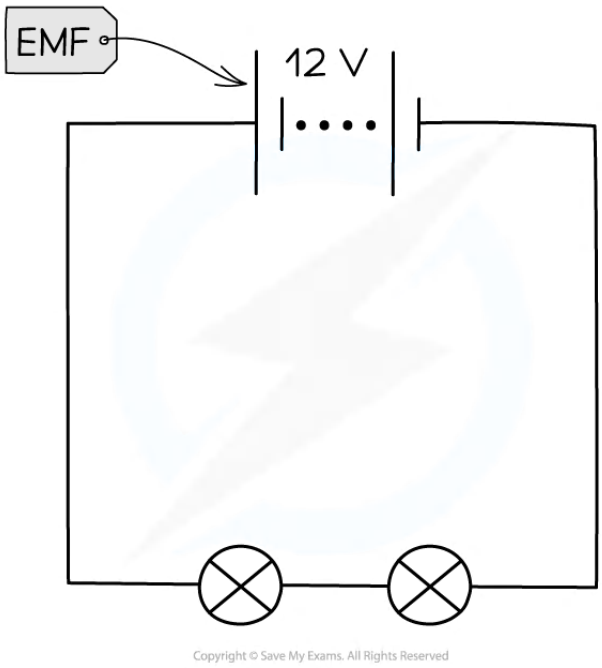
Electromotive Force

- The electromotive Force (e.m.f.) is the name given to the potential difference of the power source in a circuit
- It is defined as

The electrical work done by a source in moving a unit charge around a complete circuit

- Electromotive force (e.m.f.) is measured in volts (V)

Electromotive Force in a Circuit



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The EMF is the voltage supplied by a power supply: 12 V in the above case

- The definition of e.m.f. can also be expressed using an equation

$$E = \frac{W}{Q}$$

- Where
 - E = electromotive force (e.m.f.) (V)
 - W = energy supplied **to the charges** from the power source (J)

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- Q = charge on each charge carrier (C)
 Note: in circuits the charge carriers are electrons
- This equation should be compared to the definition of potential difference (below) as the two are closely related


Your notes

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Potential Difference

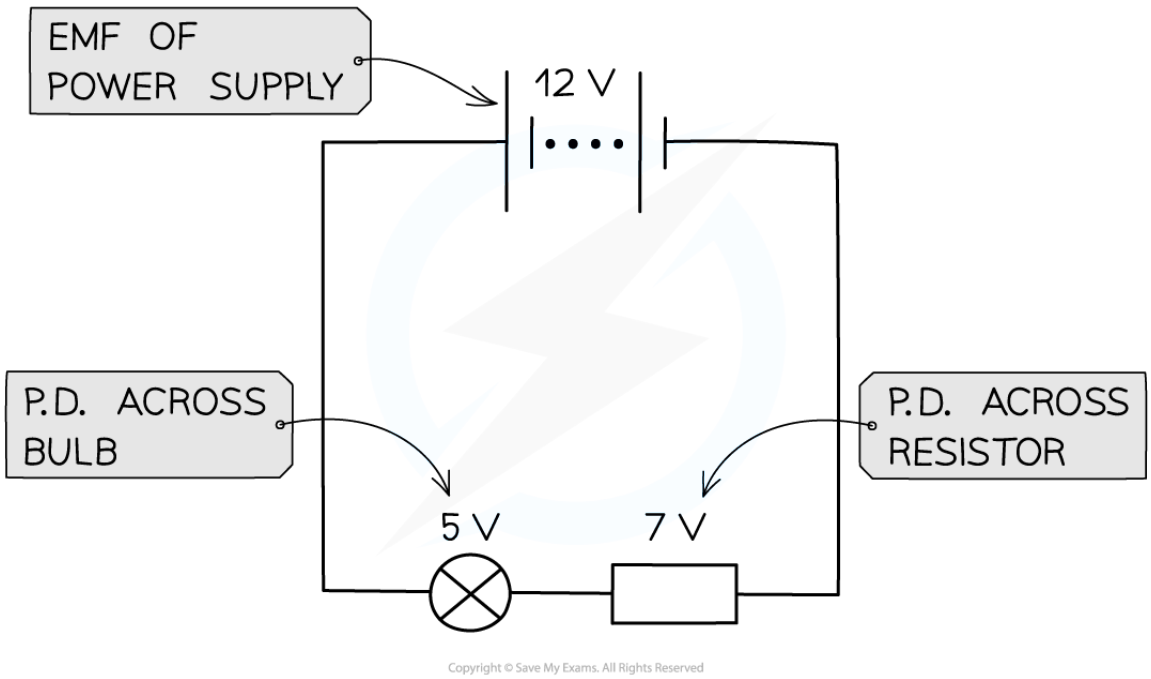
Your notes

- As charge flows around a circuit energy is transferred from the power source to the charge carriers, and then to the components
 - This is what makes components such as bulbs light up
 - The potential difference between two points in a circuit is related to the amount of energy transferred between those points in the circuit
- Potential difference is defined as

The work done by a unit charge passing through a component

- Potential difference is measure in volts (V)

Electromotive Force and Potential Difference in a Circuit



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The potential difference is the difference in the electrical potential across each component: 5 volts for the bulb (on the left) and 7 volts for the resistor (on the right)

- The definition of p.d. can also be expressed using an equation

$$V = \frac{W}{Q}$$

- Where

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- V = potential difference (p.d.) (V)
- W = energy transferred to the components **from the charge carriers** (J)
- Q = charge on each charge carrier (C)
 - *In circuits the charge carriers are electrons*
- This equation should be compared to the definition of e.m.f. as the two are closely related due to conservation of energy


Your notes

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Measuring Potential Difference

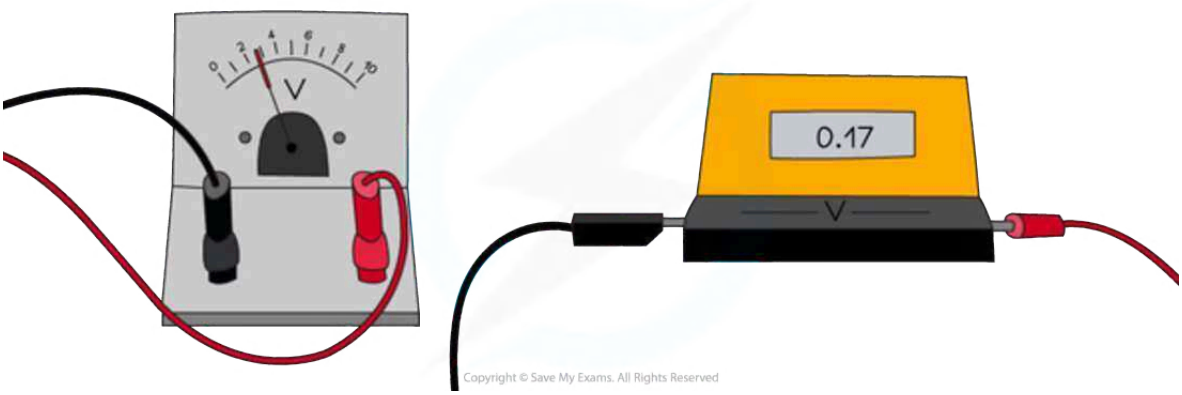
Your notes

- Potential difference is measured using a voltmeter, which can be either
 - Digital (with an electronic read out)
 - Analogue (with a needle and scale)
- Voltmeters are connected in **parallel** with the component being tested
 - The potential difference is the **difference** in electrical potential between two points, therefore the voltmeter has to be connected to **two points** in the circuit

Analogue or Digital?

- **Analogue voltmeters** are subject to parallax error
 - Always read the meter from a position directly perpendicular to the scale
- Typical ranges are 0.1–1.0 V and 0–5.0 V for analogue voltmeters although they can vary
 - Always double check exactly where the marker is before an experiment, if not at zero, you will need to subtract this from all your measurements
 - They should be checked for zero errors before using

Analogue and Digital Voltmeters



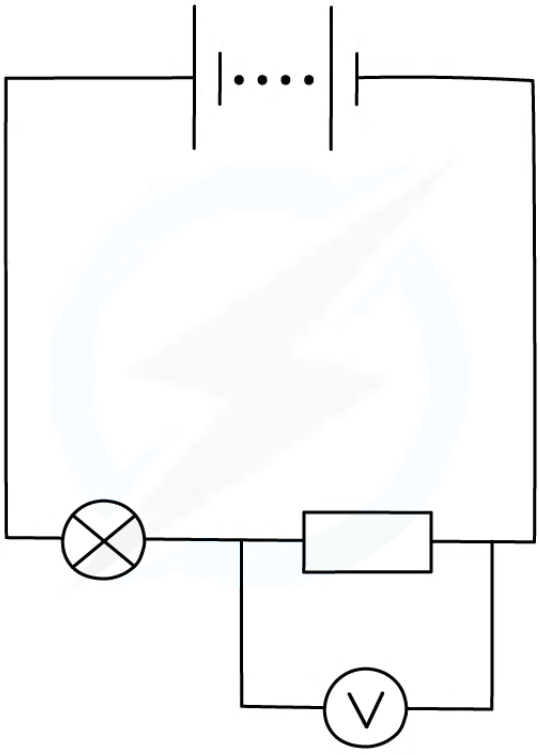
Voltmeters can be either analogue (with a scale and needle) or digital (with electronic read-out)

- **Digital voltmeters** can measure very small potential differences, in mV or μV
- Digital displays show the measured values as digits and are more accurate than analogue displays
- They're easy to use because they give a specific value and are capable of displaying more precise values
 - However digital displays may 'flicker' back and forth between values and a judgement must be made as to which to write down
- Digital voltmeters should be checked for zero error
 - Make sure the reading is zero before starting an experiment, or subtract the "zero" value from the end results

Position of a Voltmeter in a Circuit

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Your notes



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Voltmeters are connected in parallel to the component being tested

Exam Tip

When you are actually building a circuit in class, always **save the voltmeter until last.**

Make the whole circuit first and check it works.

Only then pick up the voltmeter. Connect two leads to your voltmeter. Now connect the leads so that they are one on each side of the component you are measuring. This will save you a LOT of time waiting for your teacher to troubleshoot your circuit!

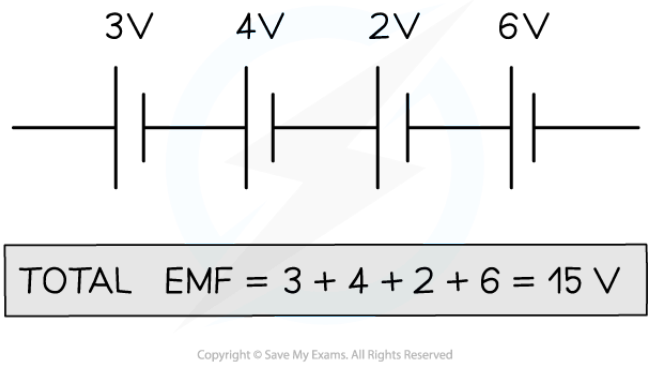
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Calculating Total EMF


Your notes

- When several cells are connected together in series, their combined EMF is equal to the sum of their individual EMFs

Total Electromotive Force



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The total EMF of these cells is equal to the sum of their individual EMFs

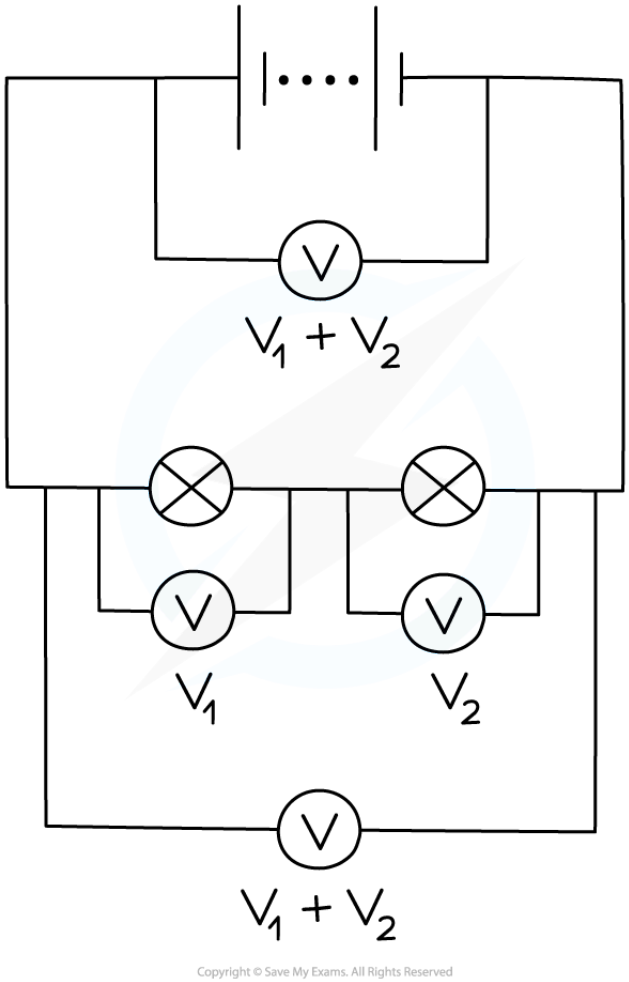
Potential Difference in Series Circuits

- In a series circuit, the sum of potential differences across the components is equal to the total EMF of the power supply

Potential Difference in Series

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Your notes



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In a series circuit the components share the EMF of the power supply

Potential Difference in Parallel Circuits

- A parallel circuit consists of two or more components attached along separate branches of the circuit

Parallel Circuit

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Your notes

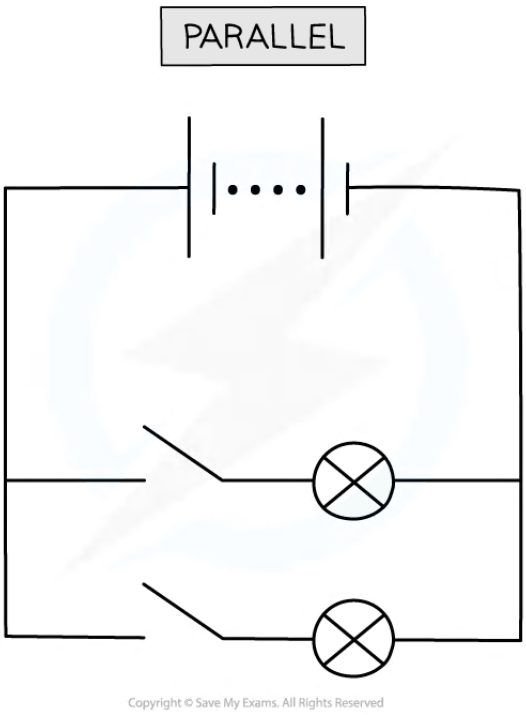


Diagram showing two bulbs connected in parallel

- The **advantages** of this kind of circuit are:
 - **The components can be individually controlled, using their own switches**
 - **If one component stops working the others will continue to function**
- **In a parallel circuit, the current splits up** - some of it going one way and the rest going the other
- This means that the current in each branch will be smaller than the current from the power supply

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Resistance

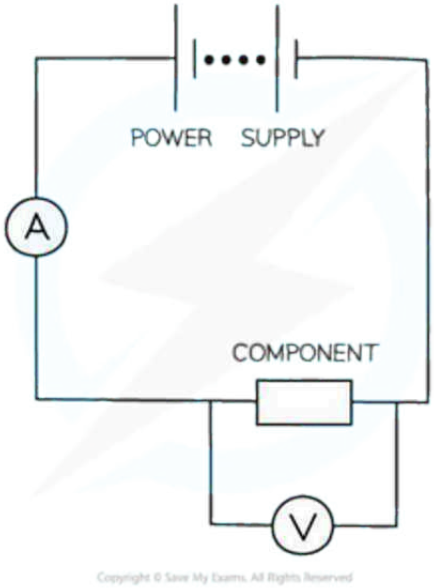
Your notes

Determining Resistance

Determining Resistance

- To find the resistance of a component, we can set up a circuit like the one shown below

Circuit Set-up for Determining Resistance



A circuit to determine the resistance of a component includes a power supply, an ammeter connected in series, and a voltmeter connected in parallel to the component being measured

- The power supply should be set to a low voltage to avoid heating the component, typically 1–2 V
- Measurements of the potential difference and current should then be taken from the voltmeter and ammeter respectively
- Finally, these readings should be substituted into the resistance equation

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Worked example

A charge of 5.0 C passes through a resistor of resistance R Ω at a constant rate in 30 s.

The potential difference across the resistor is 2.0 V. Calculate the value of R.

Answer:

Step 1: List the known quantities

- Charge, Q = 5.0 C
- Time, *t* = 30 s
- Potential difference, *V* = 2.0 V

Step 2: Rearrange the current & charge equation to make current the subject

$$Q = It$$

$$I = \frac{Q}{t}$$

Step 3: Substitute the known values to calculate

$$I = \frac{5.0}{3.0}$$

$$I = 0.167 \text{ A}$$

Step 4: Substitute the known values into the resistance equation to calculate

$$R = \frac{V}{I}$$

$$R = \frac{2.0}{0.167}$$

$$R = 12.0 \, \Omega$$

Your notes

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Ohm's Law


Your notes

Resistance is the opposition to current

- For a given potential difference, the **higher the resistance, the lower the current**
- Therefore resistors are used in circuits to control the current
- The unit of resistance is the **ohm**, represented by the Greek symbol omega **Ω**

Ohm's Law

- The definition of resistance can be given using the equation

$$R = \frac{V}{I}$$

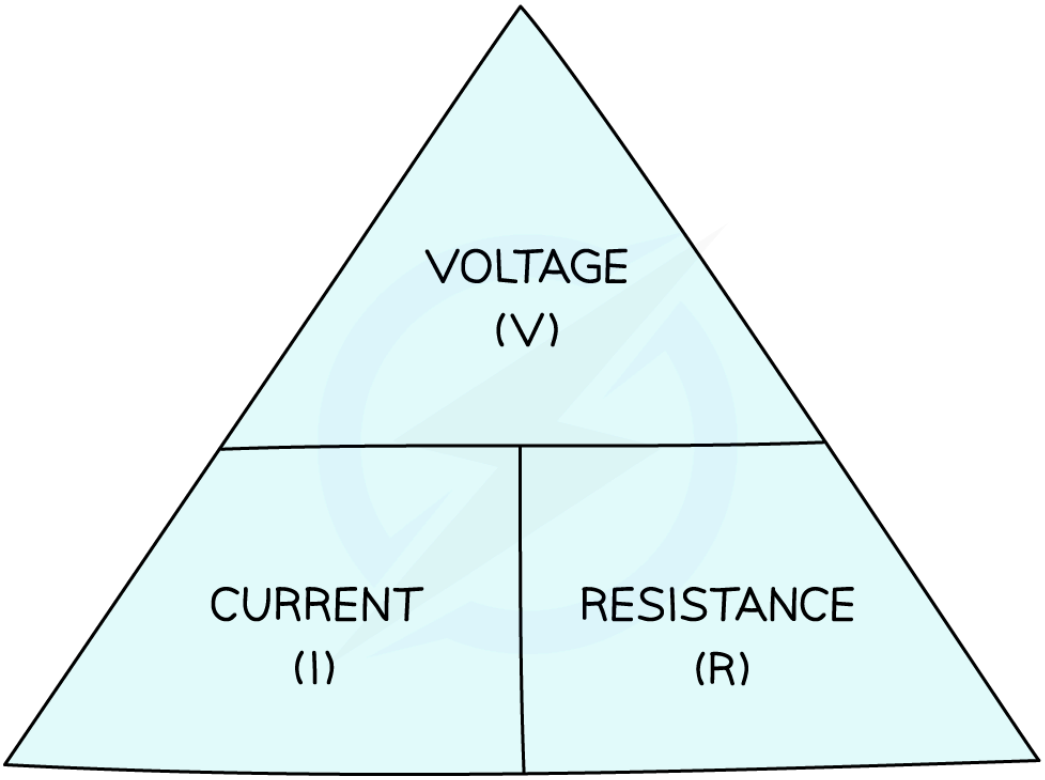
- Where
 - R = resistance (ohms, Ω)
 - V = potential difference (volts, V)
 - I = current (amperes, A)
- Ohm's Law can be stated in words:

Current is directly proportional to potential difference as long as the temperature remains constant

Equation Triangle for Ohm's Law

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Your notes



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Use the formula triangle to help you rearrange the equation until you feel confident to do it unaided

Consequences of Ohm's Law

- Resistors are used in circuits to control either
 - The current in branches of the circuit (through certain components)
 - The potential difference across certain components
- This is due to the consequences of Ohm's Law
 - The current in an electrical conductor decreases as its resistance increases (for a constant p.d.)
 - The p.d. across an electrical conductor increases as its resistance increases (for a constant current)

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Resistance of a Wire

Your notes

Proportionality Relationships for Electrical Conductors

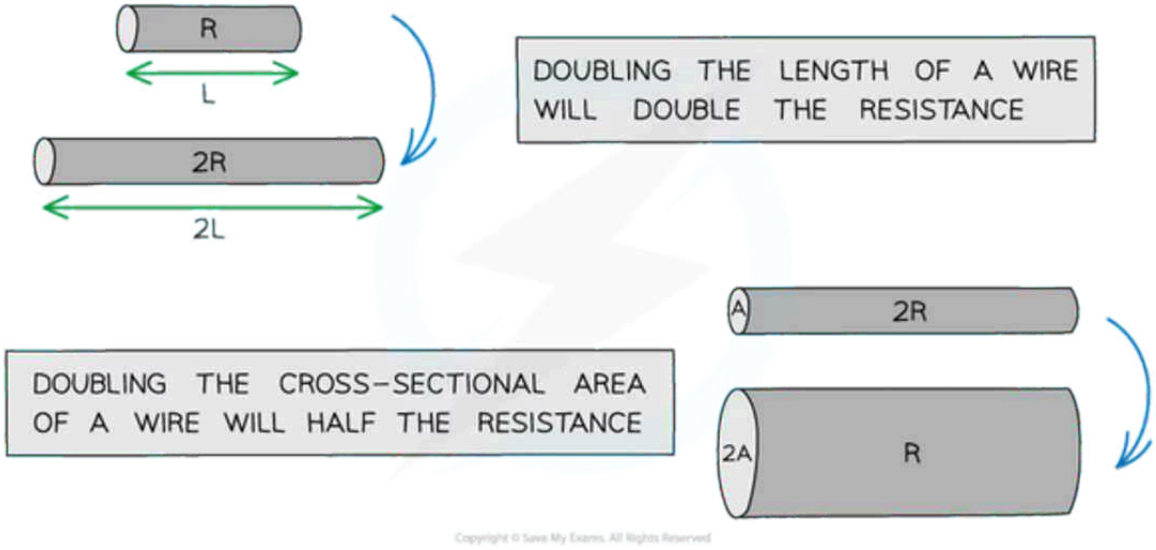
- The relationship between resistance, length and cross-sectional area can be represented mathematically
 - Resistance is **directly** proportional to **length**

$$R \propto L$$

 - Resistance is **inversely** proportional to **cross-sectional area** (width, or thickness)

$$R \propto \frac{1}{A}$$

Proportional Relationships Between Resistance, Length & Cross-Sectional Area



Resistance is directly proportional to the length of the wire and indirectly proportional to the cross-sectional area

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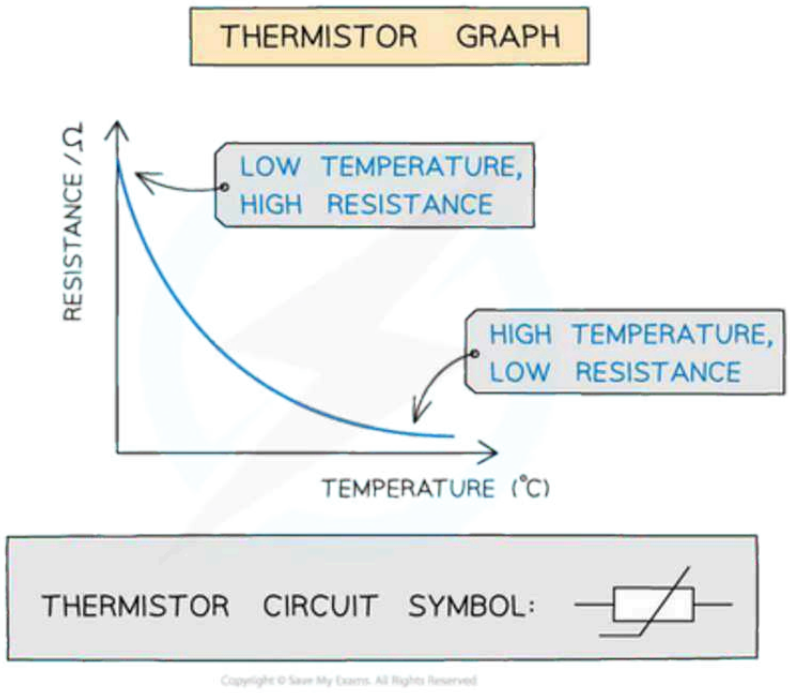
Effect of Temperature on Resistance

Your notes

- The resistivity of a thermistor behaves in the **opposite** way to metals
 - This is because it is a type of semiconductor
 - Semiconductors behave in a different way to metals
- The number density of charge carriers (such as electrons) **increases** with **increasing** temperature
- Therefore, for a thermistor:
 - An **increase** in temperature causes a **decrease** in resistance and resistivity
 - A **decrease** in temperature causes an **increase** in resistance and resistivity

- Thermistors are often used in temperature sensing circuits such as thermometers and thermostats
- A thermistor is a non-ohmic conductor and sensory resistor whose resistance varies with temperature
 - Most thermistors are negative temperature coefficient ntc) components.
 - This means that if the temperature **increases,** the resistance of the thermistor **decreases** (and vice versa)

Resistance-Temperature Graph for a Thermistor



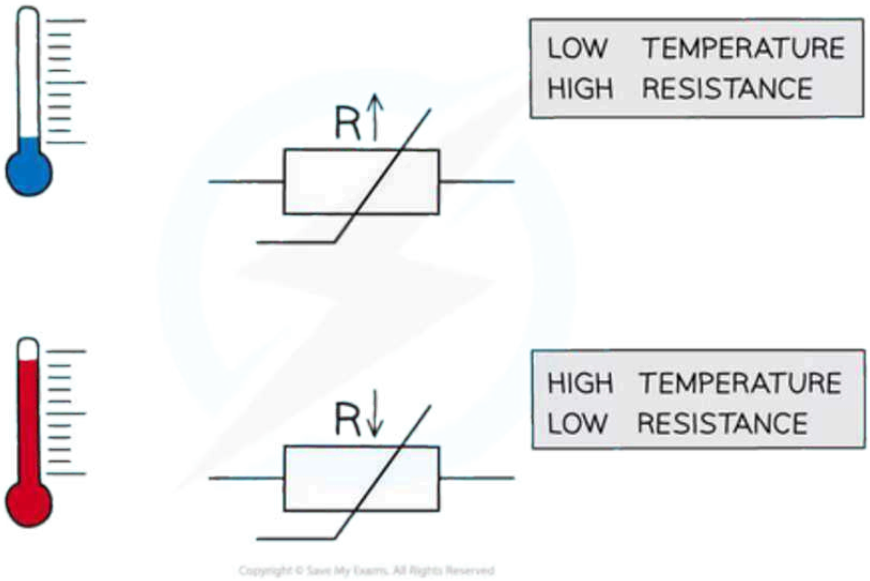
Resistance decreases as temperature increases for a thermistor

- Thermistors are temperature sensors and are used in circuits in ovens, fire alarms and digital thermometers
 - As the thermistor gets **hotter**, its resistance **decreases**

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- As the thermistor gets **cooler**, its resistance **increases**

Effect of Temperature on a Thermistor



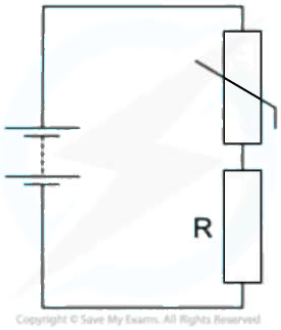
A thermistor has a high resistance at low temperatures and a low resistance at high temperatures

Your notes

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Worked example

A thermistor is connected in series with a resistor *R* and a battery.



The resistance of the thermistor is equal to the resistance of *R* at room temperature.

Which statement describes the effect when the temperature of the thermistor decreases?

A. The p.d across the thermistor increases

B. The current in *R* increases

C. The current through the thermistor decreases

D. The p.d across *R* increases

Answer: A

Step 1: Outline the nature of a thermistor

- The resistance of the thermistor increases as the temperature decreases

Step 2: Consider the properties of current in a series circuit

- Since the thermistor and resistor *R* are connected in series, the current *I* in both of them is the same

Step 3: Consider a relevant equation

- Ohm's law states that $V = IR$
- Since the resistance of the thermistor increases, and *I* is the same, the potential difference *V* across it increases

Step 4: State the conclusion

- Therefore, statement **A** is correct

Your notes

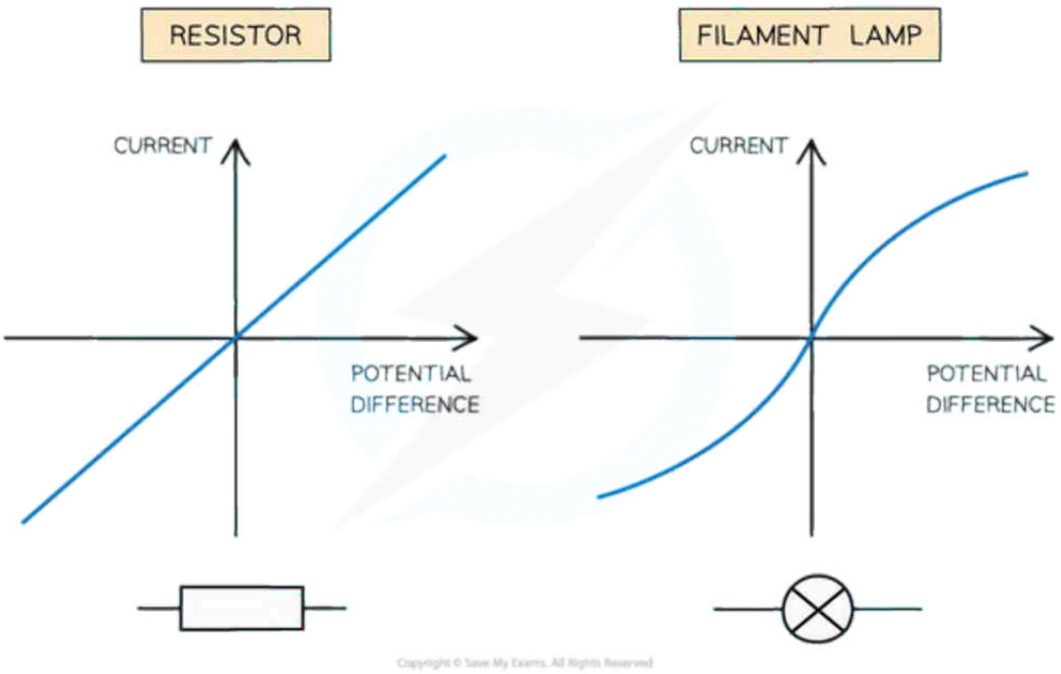
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I-V Graphs for Ohmic Resistors, Filament Lamps & Diodes

Your notes

- As the **potential difference** (voltage) across a component is **increased**, the **current** in the component also **increases**
- The precise relationship between voltage and current can be different for different types of components and is shown by an IV graph:

IV Graphs for a Resistor & a Filament Lamp



The IV graph for a resistor is a straight line through the origin, the resistance for a filament lamp changes with temperature

- The IV graph **for a resistor** is very simple:
 The current is proportional to the potential difference
- This is because the resistor has a **constant** resistance

- **For a lamp** the relationship is more complicated:
 The current increases at a proportionally slower rate than the potential difference
- This is because:

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- The current causes the filament in the lamp to **heat up**
- As the filament gets hot, its **resistance increases**
- This opposes the current, causing it to increase at a **slower rate**


Your notes

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Cambridge O Level Physics

Your notes

4.3 Electric Circuits

Contents

- Circuit Diagrams & Circuit Components
- Current in Circuits
- Potential Difference in Circuits
- Combined Resistance
- Potential Dividers

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Circuit Diagrams & Circuit Components


Your notes

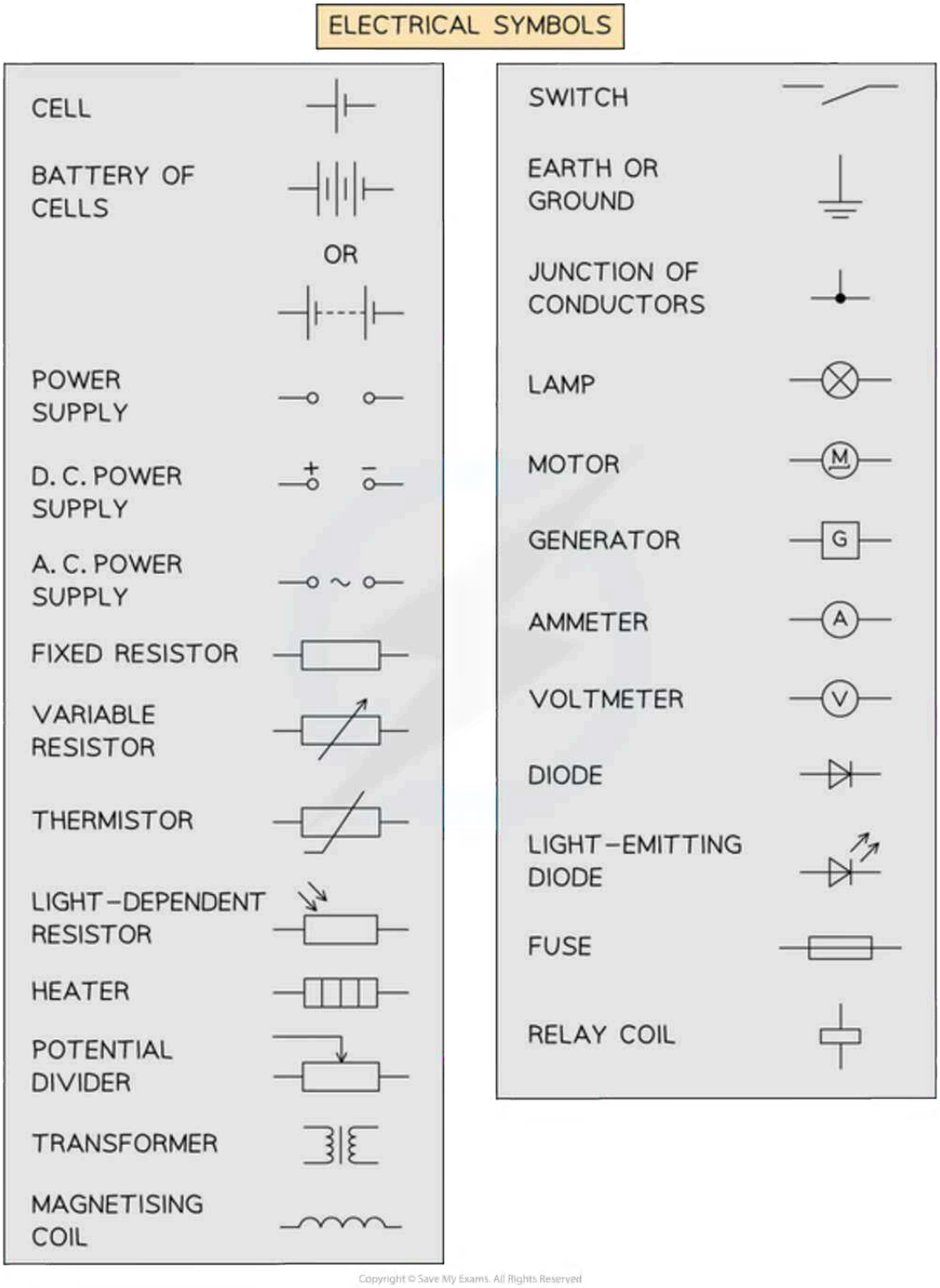
Circuit Components

- The diagram below shows the circuit symbols that could be used in circuit diagrams
 - You will be expected to know **what each component is** and **how it behaves** in a circuit

Circuit Symbols

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Your notes



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Your notes

Common circuit symbols used in circuit diagrams

Power supplies

- Cells, batteries, power supplies and generators all **supply current** to the circuit

Resistors

- Potential dividers, fixed and variable resistors, thermistors and light-dependent resistors (LDRs) are all used to **control current**

Meters

- Ammeters and voltmeters are used to measure the current and potential difference
 - Ammeters are always connected in series whilst voltmeters are always connected in parallel

Electromagnetic Components

- Magnetising coils, relays and transformers use electromagnetic effects
 - Relays use a small current in one circuit to switch on a much larger current in another
 - Transformers 'step up' and 'step down' current and potential difference

Fuses

- Protect expensive components from current surges and act as a safety measure against fire

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Diodes

Your notes

- A light-emitting diode (LED) is a type of semiconductor diode that emits light when current flows in a specific direction
- The different colours of an LED are determined by the type of semiconductor material used such as:
 - Aluminium Gallium Phosphide (AlGaP) – green
 - Zinc Selenide (ZnSe) - blue
- LEDs only requires a current of 20 mA to produce a light output or a voltage of about 2 V

Circuit Symbol for a Light Emitting Diode (LED)



For light to be emitted, current will be flowing from left to right in the direction the triangle is pointing; the arrows pointing away from the diode represent light rays being emitted

- They are an efficient way of indicating the state of an output in electronic circuits
 - For example, which path the current is flowing through when switches and relays are used
- LEDs are likely to be connected to series resistors to limit the current flow so they don't become overloaded
- Remember that LEDs will emit light when they are forward biased in the same direction as **conventional** current flow (positive to negative) and will **not** emit light when in the opposite direction to the current flow

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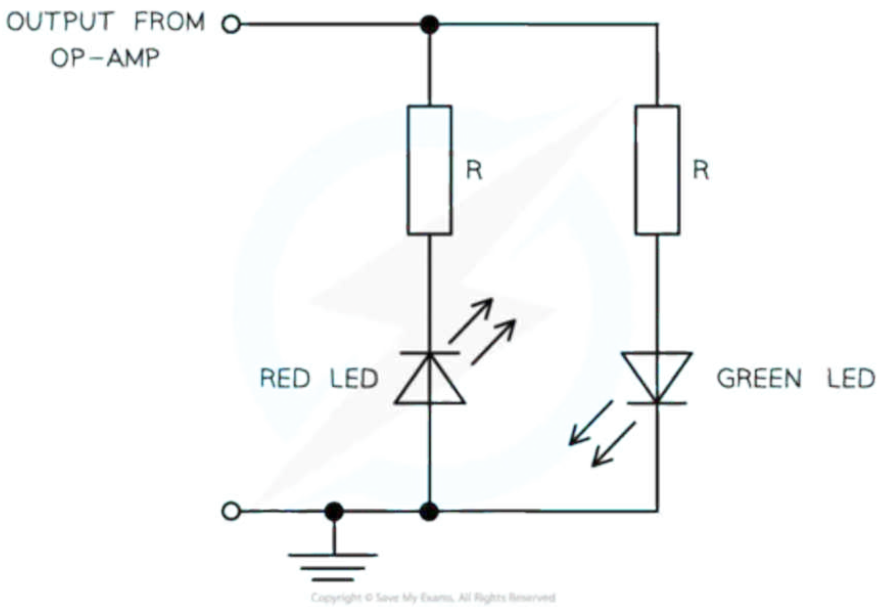
Your notes

Worked example

From the circuit diagram below, determine which LED will light up when the output of the op-amp is:

(a) Positive relative to earth

(b) Negative relative to earth



Answer:

(a)

Step 1: Determine which direction the current is flowing in

- When the op-amp is positive the current is flowing from top to bottom

Step 2: Determine which LED is forward biased in the same direction

- The green LED is forward biased when the current flows from top to bottom (is in the same direction as the current) therefore this will emit light

(b)

Step 1: Determine which direction the current is flowing in

- When the op-amp is negative the current is flowing from bottom to top

Step 2: Determine which LED is forward biased in the same direction

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- The red LED is forward biased when the current flows from bottom to top (is in the same direction as the current) therefore this will emit light



Your notes

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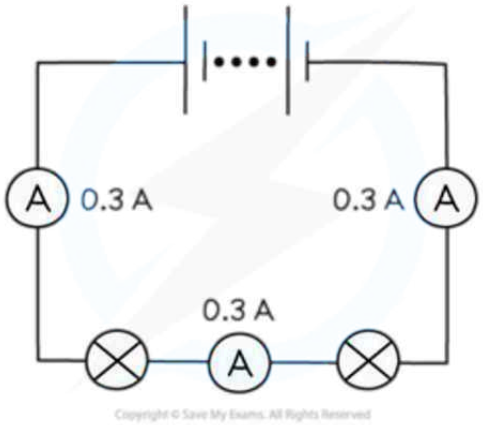
Current in Circuits

Your notes

Current in Series Circuits

- In a circuit that is a closed-loop, such as a series circuit, the current is the **same value at any point**
 - This is because the number of electrons per second that passes through one part of the circuit is the same number that passes through any other part
- This means that **all** components in a closed-loop have the same current

Current in a Series Circuit

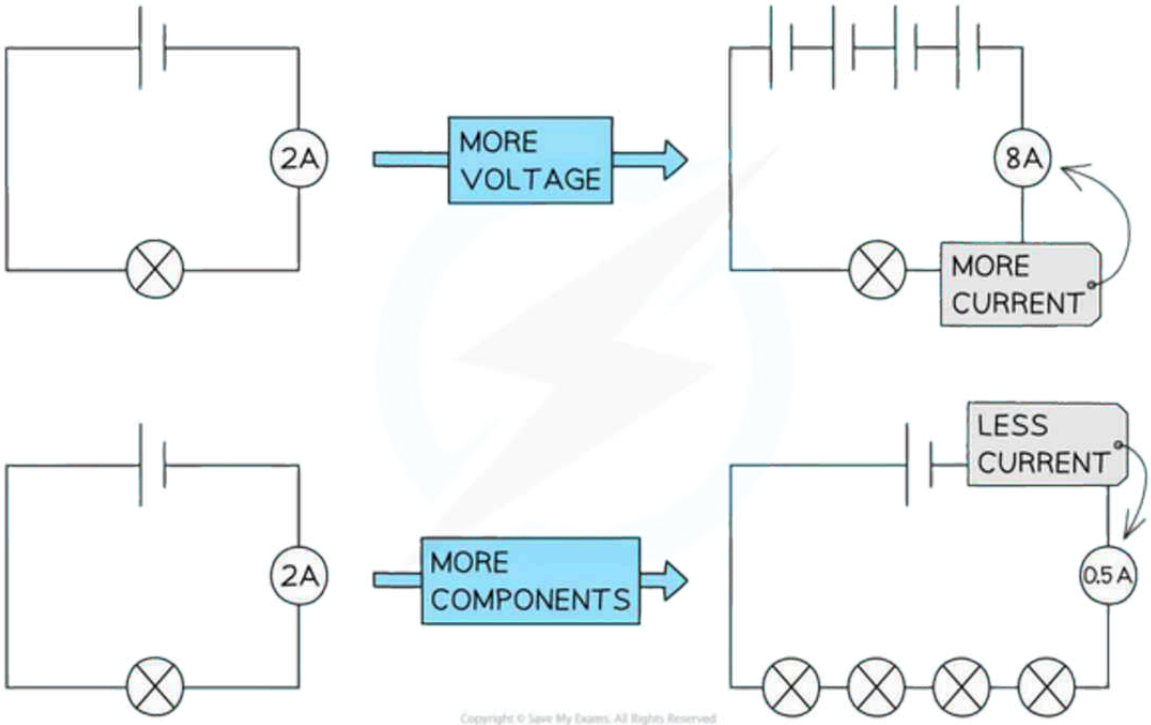


The current is the same at each point in a closed-loop

- The amount of current flowing around a series circuit depends on two things:
 - The **voltage** of the power source
 - The **resistance** of the components in the circuit
- **Increasing** the **voltage** of the power source drives **more current** around the circuit
 - So, decreasing the voltage of the power source reduces the current
- **Increasing** the **number** of components in the circuit **increases** the **total resistance**
 - Hence **less current** flows through the circuit

Increasing Potential Difference & Adding Components

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Current will increase if the voltage of the power supply increases, and decreases if the number of components increases (because there will be more resistance)

Your notes

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Current in Parallel Circuits

Your notes

- A parallel circuit consists of two or more components attached along separate branches of the circuit

Current in a Parallel Circuit

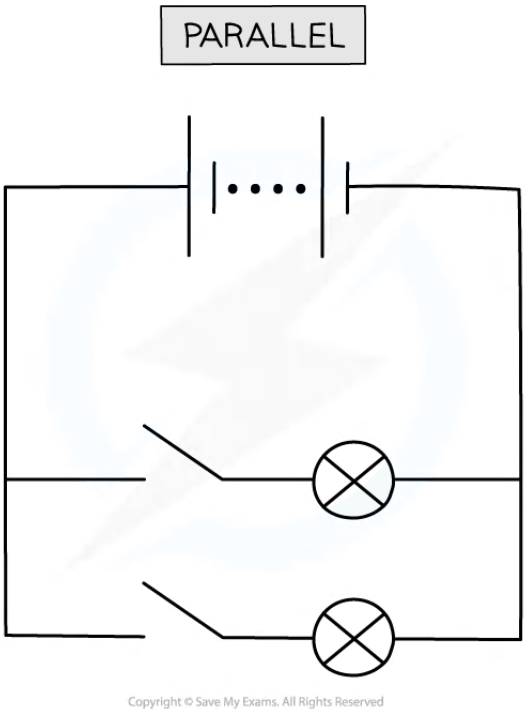


Diagram showing two bulbs connected in parallel

- The **advantages** of this kind of circuit are:
 - **The components can be individually controlled, using their own switches**
 - **If one component stops working the others will continue to function**
- **In a parallel circuit, the current splits up** - some of it going one way and the rest going the other
- This means that the current in each branch will be smaller than the current from the power supply
- At a **junction** in a **parallel circuit** (where two or more wires meet) the current is **conserved**
 - This means the amount of current flowing into the junction is equal to the amount of current flowing out of it
- This is because **charge** is conserved
- Note that the current does not always split equally – often there will be more current in some branches than in others

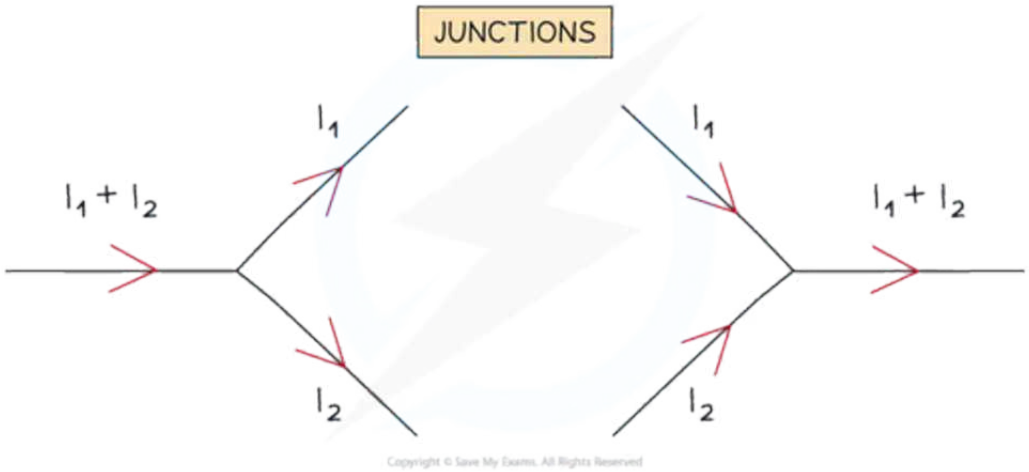
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- The current in each branch will only be identical if the **resistance** of the components along each branch are **identical**

- Current behaves in this way because it is the **flow of electrons**:
 - Electrons are physical matter – they cannot be created or destroyed
 - This means the total number of electrons (and hence current) going around a circuit must remain the same
 - When the electrons reach a junction, however, some of them will go one way and the rest will go the other

Your notes

Current at Junctions



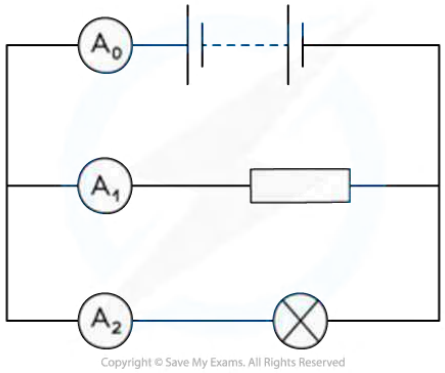
Current is conserved a junction; the total current is the sum of the current in the individual branches

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Your notes

Worked example

In the circuit below, ammeter A_0 shows a reading of 10 A, and ammeter A_1 shows a reading of 6 A.



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State the reading on ammeter A_2

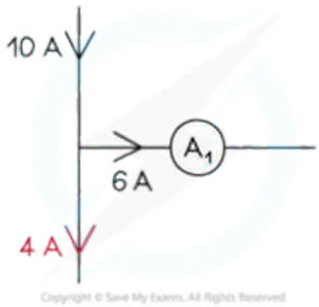
Answer:

Step 1: Recall that at a junction, the current is conserved

- This means that the total amount of current flowing into a junction is equal to the total amount flowing out

Step 2: Consider the first junction in the circuit where current splits

- The diagram below shows the first junction in the circuit



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Step 3: Calculate the missing amount of current

- Since 10 A flows in to the junction (the total current from the battery), 10 A must flow out of the junction
- The question says that 6 A flows through ammeter A_1 so the remaining current flowing through ammeter A_2 must be:

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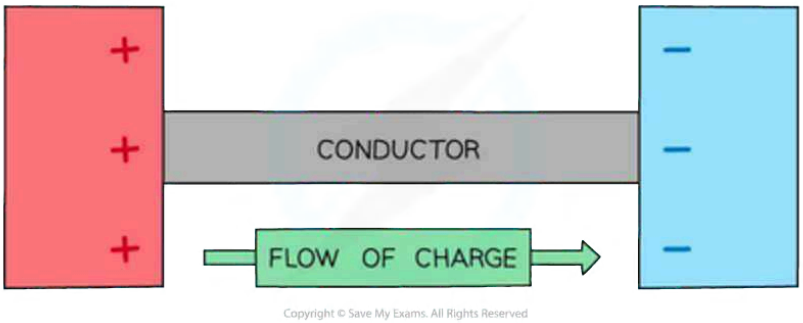
$10\ A - 6\ A = \mathbf{4\ A}$

- Therefore, **4 A** flows through ammeter A_2

Your notes

Exam Tip

The direction of current flow is super important when considering junctions in a circuit. You should remember that current flows from the **positive** terminal to the **negative** terminal of a cell / battery. This will help determine the direction current is flowing 'in' to a junction and which way the current then flows 'out'.



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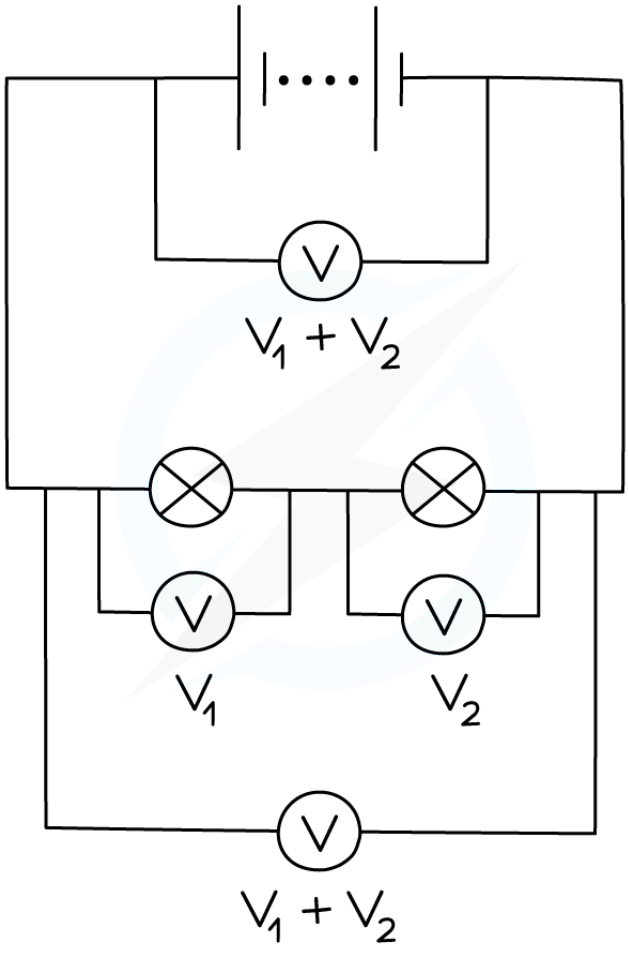
Potential Difference in Circuits

Your notes

Potential Difference in Series Circuits

- In a series circuit, the sum of potential differences across the components is equal to the total potential difference of the power supply

Potential Difference in a Series Circuit



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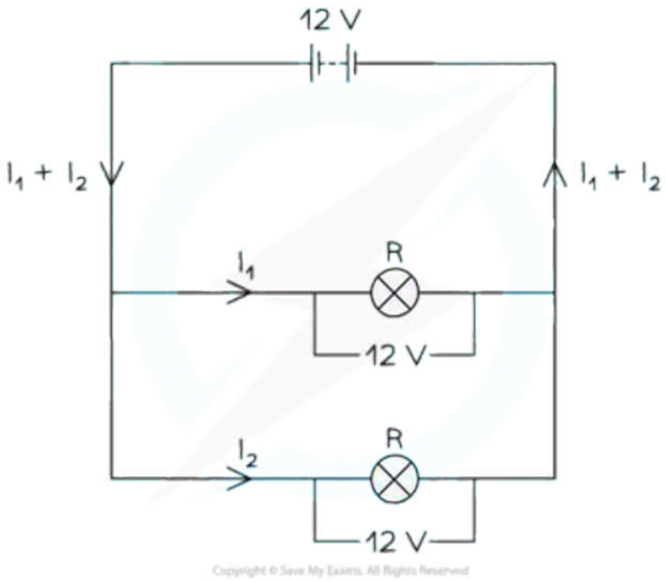
In a series circuit the components share the potential difference of the power supply

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Potential Difference in Parallel Circuits

Your notes

- In a parallel circuit:
 - The **potential difference** across each branch is the **same**
 - If components are placed in **series** within a **branch**, then the potential difference is split across the components within the branch in accordance with the rules of potential difference in series



Lamps connected in a parallel circuit

- In the above circuit:
 - If the battery is marked **12 V**, then the potential difference would be **12 V** across each lamp

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Combined Resistance

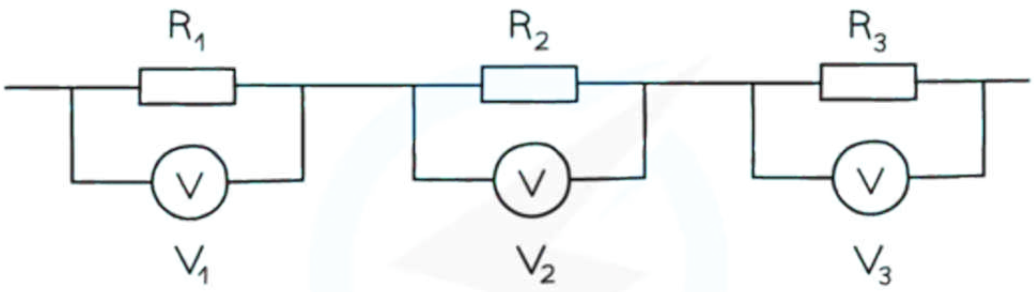
Your notes

Resistors in Series & Parallel

Resistors in Series

- When two or more components are connected in series:
 - **The combined resistance of the components is equal to the sum of individual resistances**

Combined Resistance in Series



TOTAL VOLTAGE = $V_1 + V_2 + V_3$

COMBINED RESISTANCE = $R_1 + R_2 + R_3$

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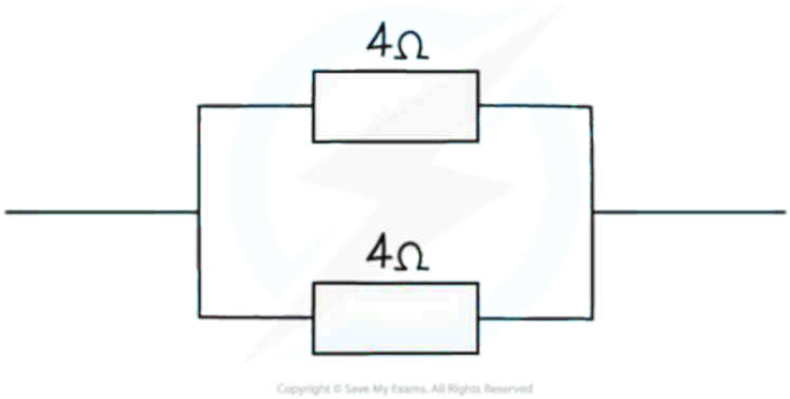
When several components are connected in series, their combined resistance is equal to the sum of their individual resistances

Resistors in Parallel

- When resistors are connected in parallel, the combined resistance decreases and is less than the resistance of any of the individual components
- If two resistors of equal resistance are connected in parallel, then the combined resistance will halve

Combined Resistance in Parallel

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The above resistors will have a combined resistance of 2 Ω – half the value of each resistor

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Potential Dividers

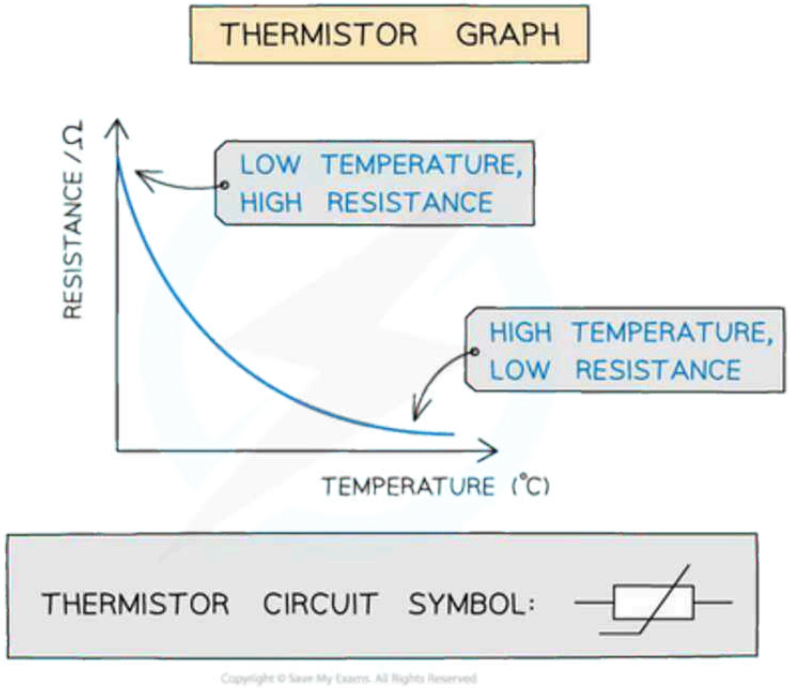
Your notes

Input Sensors

Thermistors

- A thermistor is a non-ohmic conductor and sensory resistor whose resistance varies with temperature
- Most thermistors are **negative temperature coefficient** (NTC) components.
 - This means that if the temperature **increases,** the resistance of the thermistor **decreases** (and vice versa)

Resistance-Temperature Graph for a NTC Thermistor



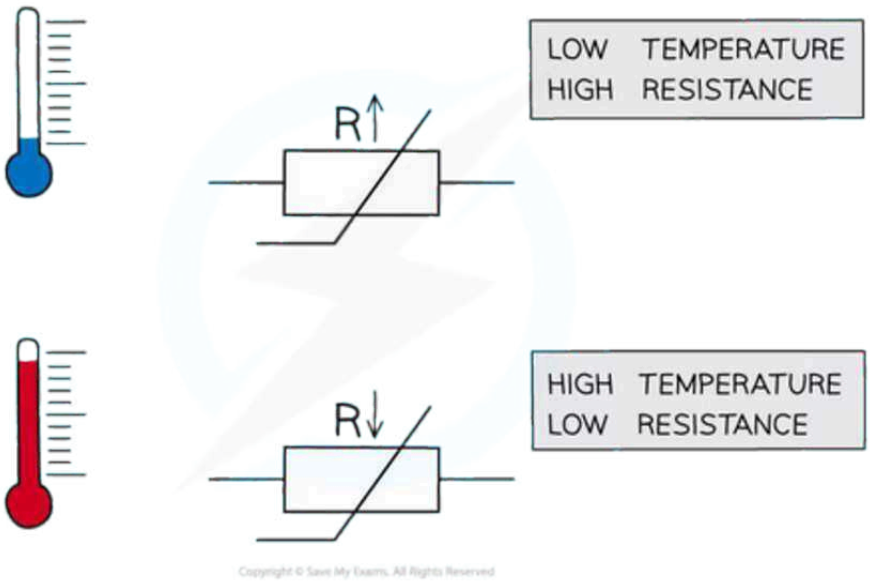
A graph of temperature against resistance for a thermistor shows that as temperature increases, resistance decreases

- Thermistors are temperature sensors and are used in circuits in ovens, fire alarms and digital thermometers
 - As the thermistor gets **hotter**, its resistance **decreases**
 - As the thermistor gets **cooler**, its resistance **increases**

Relationship Between Resistance and Temperature for a Thermistor

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Your notes



The resistance through a thermistor is dependent on the temperature of it

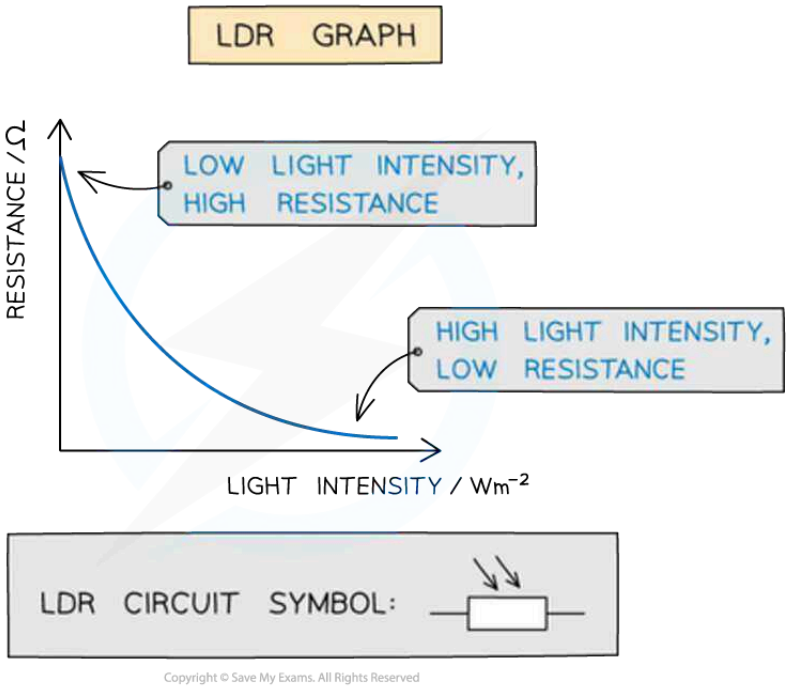
Light-Dependent Resistors

- A light-dependent resistor (LDR) is a non-ohmic conductor and sensory resistor
- Its resistance automatically changes depending on the light energy falling onto it (illumination)
- As the **light intensity increases**, the **resistance** of an LDR **decreases**

Resistance-Temperature Graph for a Light-Dependent Resistor

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Your notes



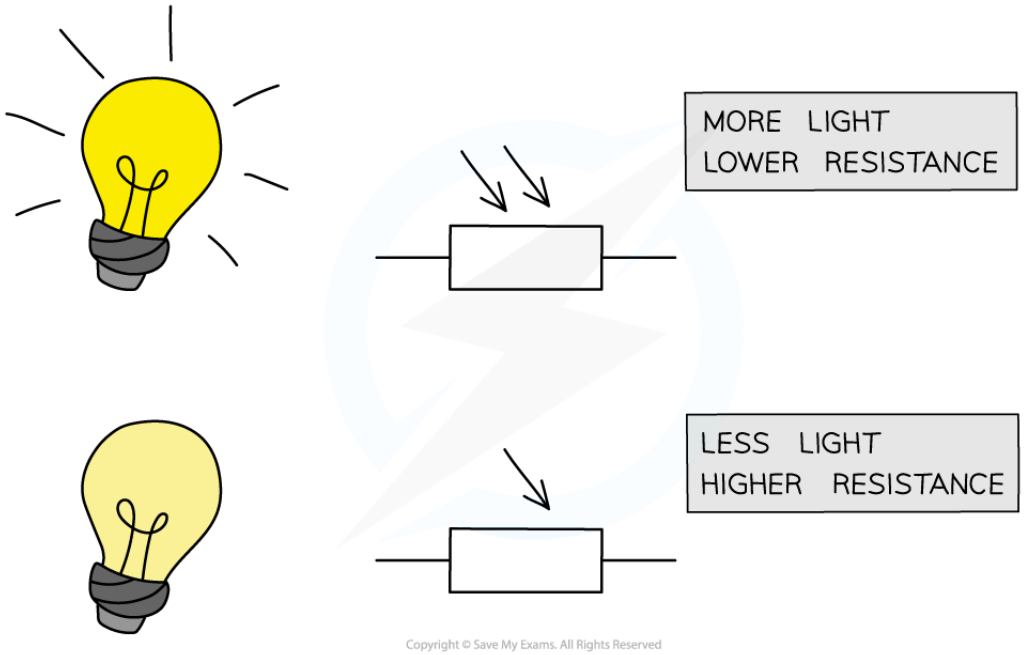
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A graph of resistance against light intensity for an LDR shows that as light intensity increases, resistance decreases

- LDRs can be used as light sensors, so, they are useful in circuits which automatically switch on lights when it gets dark, for example, street lighting and garden lights
 - In the dark, its resistance is very large (millions of ohms)
 - In bright light, its resistance is small (tens of ohms)

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Your notes



Resistance of an LDR depends on the light intensity falling on it

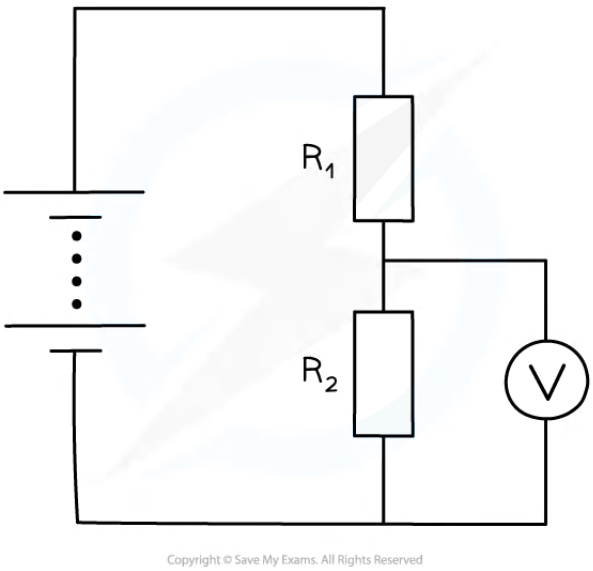
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Variable Potential Dividers

Your notes

- When two resistors are connected in series, the potential difference across the power source is shared between them

Potential Divider



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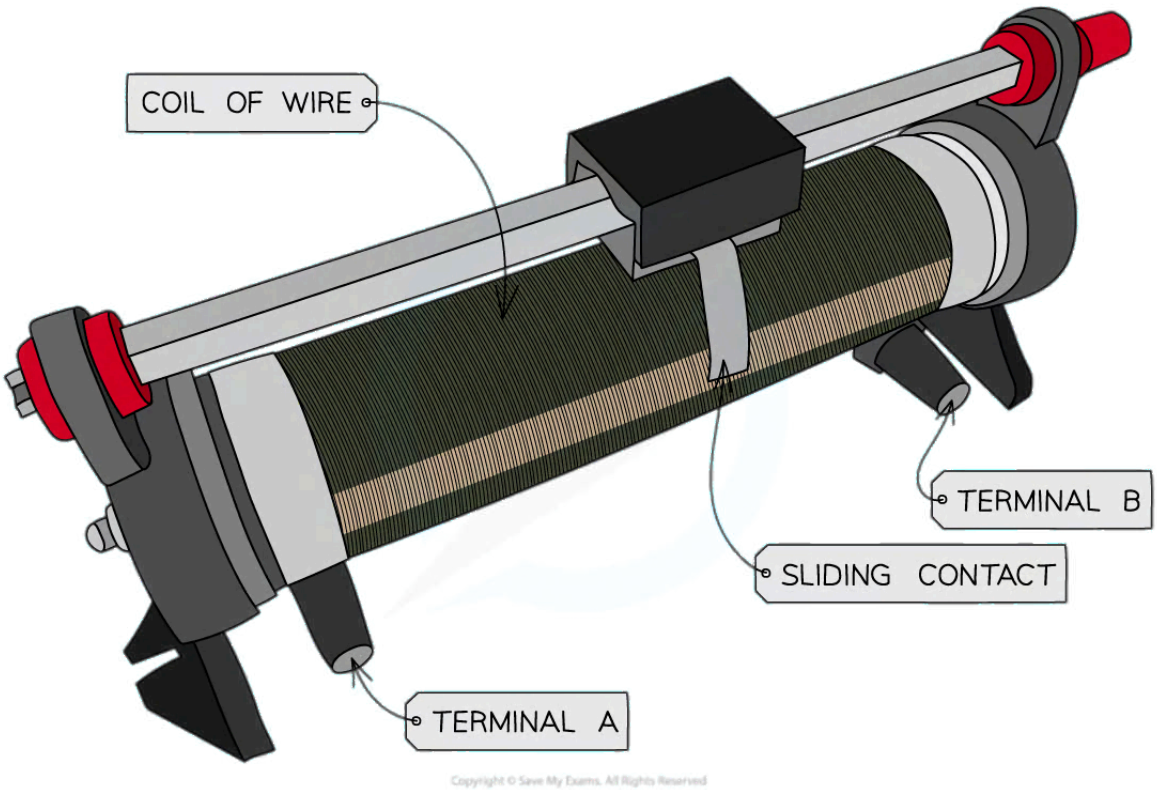
A potential divider splits the potential difference of a power source between two components

- The potential difference across each resistor depends upon its resistance:
 - The resistor with the largest resistance will have a greater potential difference than the other one
 - If the resistance of one of the resistors is increased, it will get a greater share of the potential difference, whilst the other resistor will get a smaller share
- A potentiometer is a single component that (in its simplest form) consists of a coil of wire with a sliding contact, midway along it

Potentiometer

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Your notes



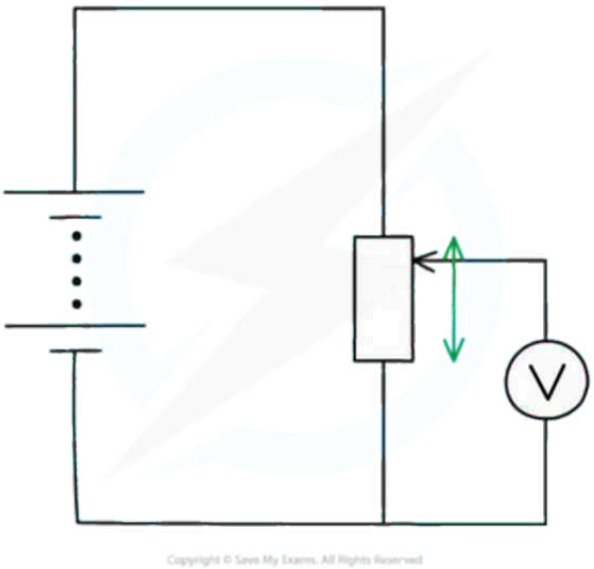
A potentiometer is a kind of variable resistor

- The sliding contact has the effect of separating the potentiometer into two parts – an upper part and a lower part – both of which have different resistances

Circuit Diagram Using a Potentiometer

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Your notes



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Moving the slider (the arrow in the diagram) changes the resistances (and hence potential differences) of the upper and lower parts of the potentiometer

- If the slider in the above diagram is moved upwards, the resistance of the lower part will increase and so the potential difference across it will also increase

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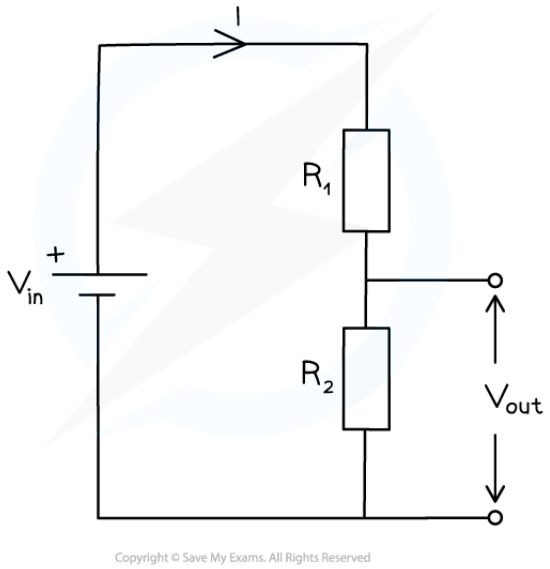
Resistors as Potential Dividers

Your notes

- When two resistors are connected in series, through Kirchhoff's Second Law, the potential difference across the power source is divided between them
- Potential dividers are circuits which produce an output voltage as a **fraction** of its input voltage
- Potential dividers have two main purposes:
 - To provide a variable potential difference
 - To enable a specific potential difference to be chosen
 - To split the potential difference of a power source between two or more components
- Potential dividers are used widely in volume controls and sensory circuits using LDRs and thermistors
- Potential divider circuits are based on the ratio of voltage between components. This is equal to the ratio of the resistances of the resistors in the diagram below, giving the following equation:

Diagram Illustrating the Potential Divider Equation

POTENTIAL DIVIDER EQUATION: $V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$



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Potential divider diagram and equation

- The input voltage V_{in} is applied to the top and bottom of the series resistors
- The output voltage V_{out} is measured from the centre to the bottom of resistor R_2
- The potential difference *V* across each resistor depends upon its resistance *R*:

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- The resistor with the **largest resistance** will have a **greater potential difference** than the other one from $V = IR$
- If the resistance of one of the resistors is increased, it will get a greater share of the potential difference, whilst the other resistor will get a smaller share

- In potential divider circuits, the p.d across a component is proportional to its resistance from $V = IR$


Your notes

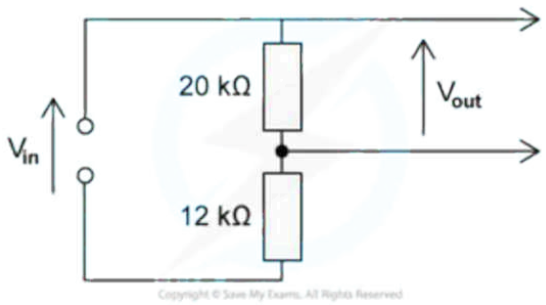
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Worked example

Your notes

The circuit is designed to light up a lamp when the input voltage exceed a preset value.

It does this by comparing V_{out} with a fixed reference voltage of 5.3 V.



V_{out} is equal to 5.3 V

Calculate the input voltage V_{in}.

Answer:

Step 1: List the known quantities

- Resistance of resistor 1, $R_1 = 20\ k\Omega$
- Resistance of resistor 2, $R_2 = 12\ k\Omega$
- Input voltage, $V_{out} = 5.3\ V$

Step 2: State the potential divider equation

$$V_{out} = \left(\frac{R_1}{R_1 + R_2} \right) V_{in}$$

Step 3: Rearrange to make input voltage the subject

- Divide both sides by $\frac{R_1}{R_1 + R_2}$

$$V_{in} = V_{out} \div \left(\frac{R_1}{R_1 + R_2} \right)$$

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$$V_{in} = V_{out} \times \left(\frac{R_1 + R_2}{R_1} \right)$$

Step 4: Substitute in the known values to calculate

$$V_{in} = 5.3 \times \left(\frac{12 + 20}{20} \right)$$

$$V_{in} = 8.5 \text{ V (2 s.f.)}$$

Exam Tip

When thinking about potential dividers, remember that the higher the resistance the more energy it will take to 'push the current through' and therefore the higher the potential difference.

This means that if a component (often shown as a voltmeter in questions) needs to be switched on by a change such as increased light or temperature, then the resistor it is in parallel with needs to become larger **compared to the other resistor.**

Your notes

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Cambridge O Level Physics

Your notes

4.4 Practical Electricity

Contents

- Electrical Safety
- Electrical Energy
- Electrical Power

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Electrical Safety


Your notes

Uses of Elelctricity

- Electricity is used in most aspects of modern day living
- As a result, the demand for electricity as a global society is immense

- Some **common uses** of electricity are:
 - Heating
 - Such as plug-in heaters, electric ovens and hobs, even gas boilers use electricity to power them
 - Lighting
 - Such as street lights, shop signs, ceiling and wall lighting, and plug-in lamps
 - Battery charging
 - For devices such as mobile phones, tablets and laptops
 - Powering motors
 - Motors are used in machines like washing machines, tumble dryers & hair dryers
 - Electronic systems
 - Such as TVs and games consoles

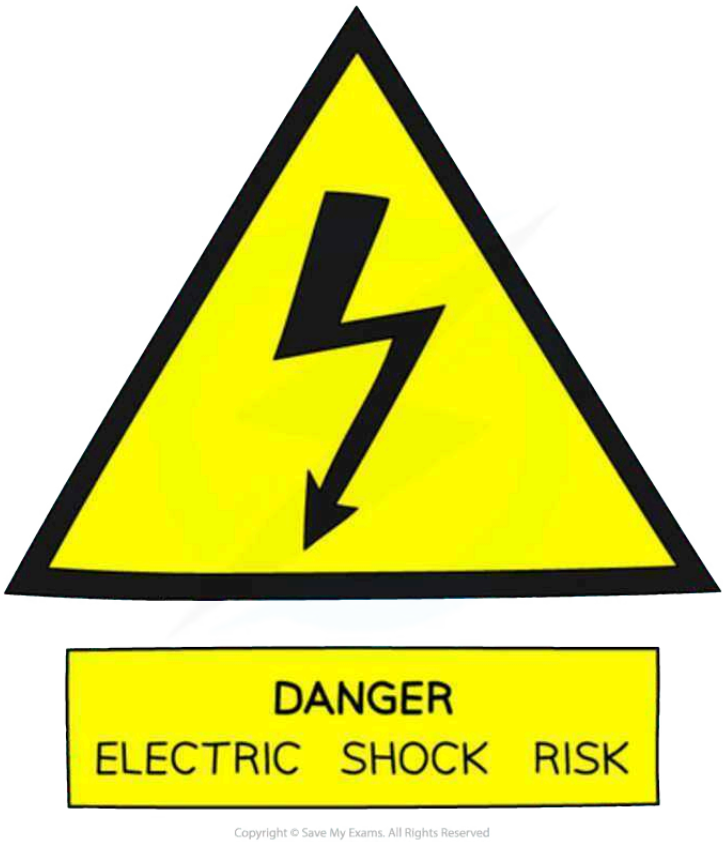
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Electrical Hazards

Your notes

- Mains electricity is potentially lethal – potential differences as small as 50 volts can pose a serious hazard to individuals

Risk of Electrocution Hazzard Symbol



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The risk of electrocution is indicated by hazard signs but other risks which would not be signposted are listed below

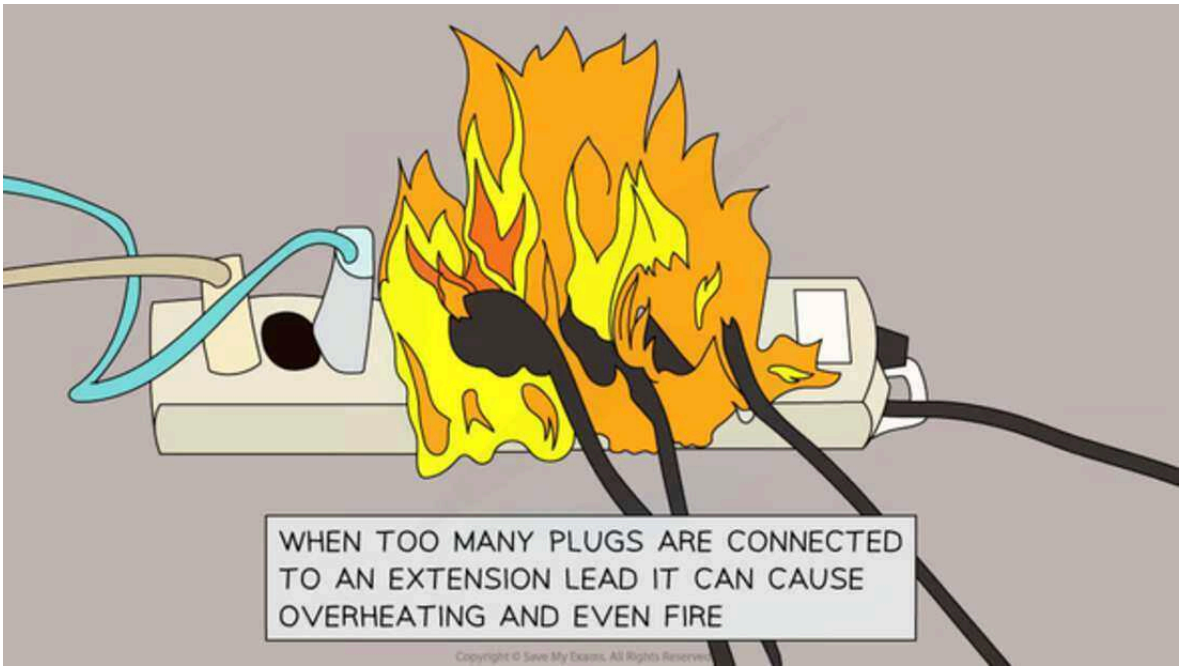
- Common hazards include:
 - **Damaged Insulation** – If someone touches an exposed piece of wire, they could be subjected to a lethal shock
 - **Overheating of cables** – Passing too much current through too small a wire (or leaving a long length of wire tightly coiled) can lead to the wire overheating. This could cause a fire or melt the insulations, exposing live wires

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- **Damp conditions** – If moisture comes into contact with live wires, the moisture could conduct electricity either causing a short circuit within a device (which could cause a fire) or posing an electrocution risk
- **Excess current from overloading of plugs, extension leads, single and multiple sockets when using a mains supply** - If plugs or sockets become overloaded due to plugging in too many components the heat created can cause fires

Your notes

Overloaded Extension Lead



Overloading extension cables can lead to overheating and in some cases, fires

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Mains Circuits

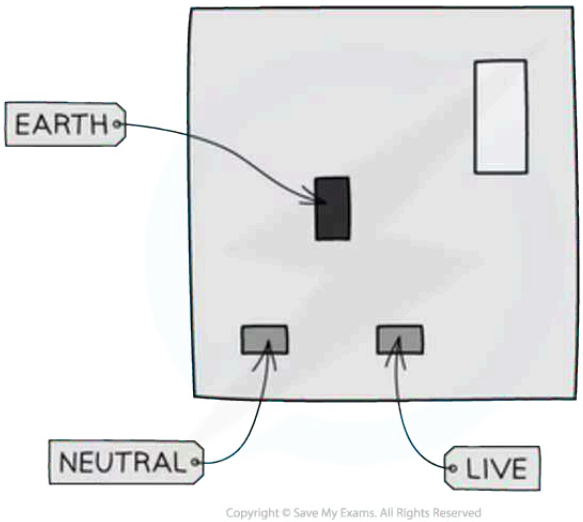
Mains Electricity

Your notes

- Mains electricity is the electricity generated by power stations and transported around the country through the National Grid
 - Everyone connects to the mains when plugging in an appliance such as a phone charger or kettle
- Mains electricity is an **alternating current** (a.c.) supply
- In the UK, the domestic electricity supply has a **frequency** of **50 Hz** and a **potential difference** of about **230 V**
 - A frequency of 50 Hz means the direction of the current changes back and forth 50 times every second
- Mains electricity, being an alternating current, does not have positive and negative sides to the power source
 - The equivalent to positive and negative are called **live** and **neutral** and these form either end of the electrical circuit

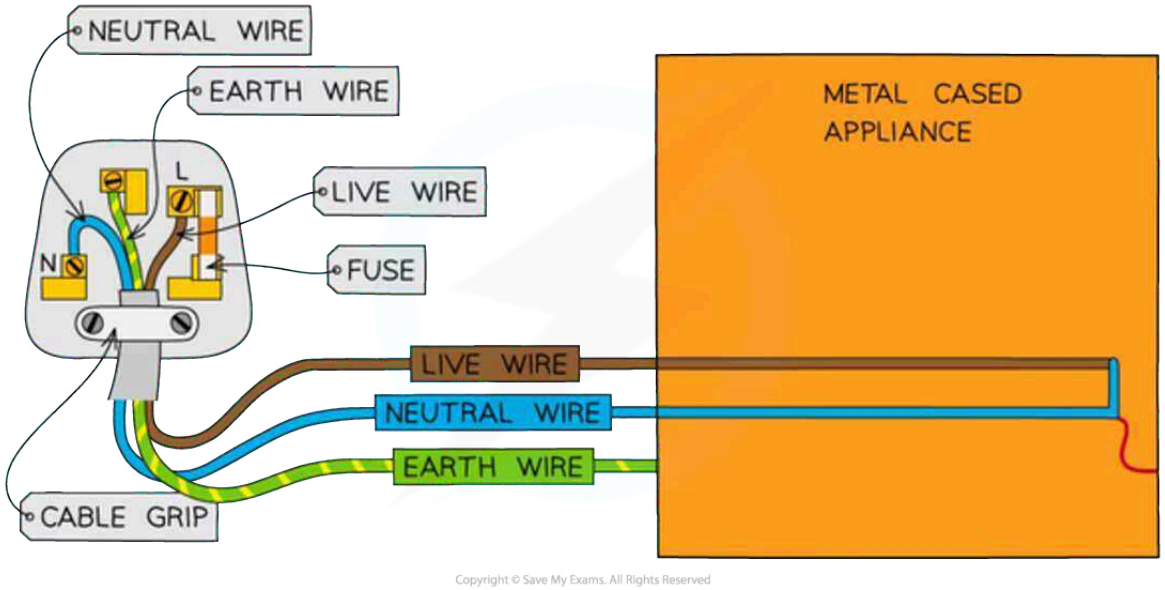
Three-pin Plug & Earth Connection

UK Plug Socket & Plug



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The plug socket and inside of a three-pin plug showing the three wires and their connections. The live and neutral wires deliver the electricity to the device. The Earth wire is for safety

In order to protect the user or the device, there are several safety features built into domestic appliances, including:

- Double insulation
- Earthing
- Fuses
- Circuit breakers

Insulation & Double Insulation

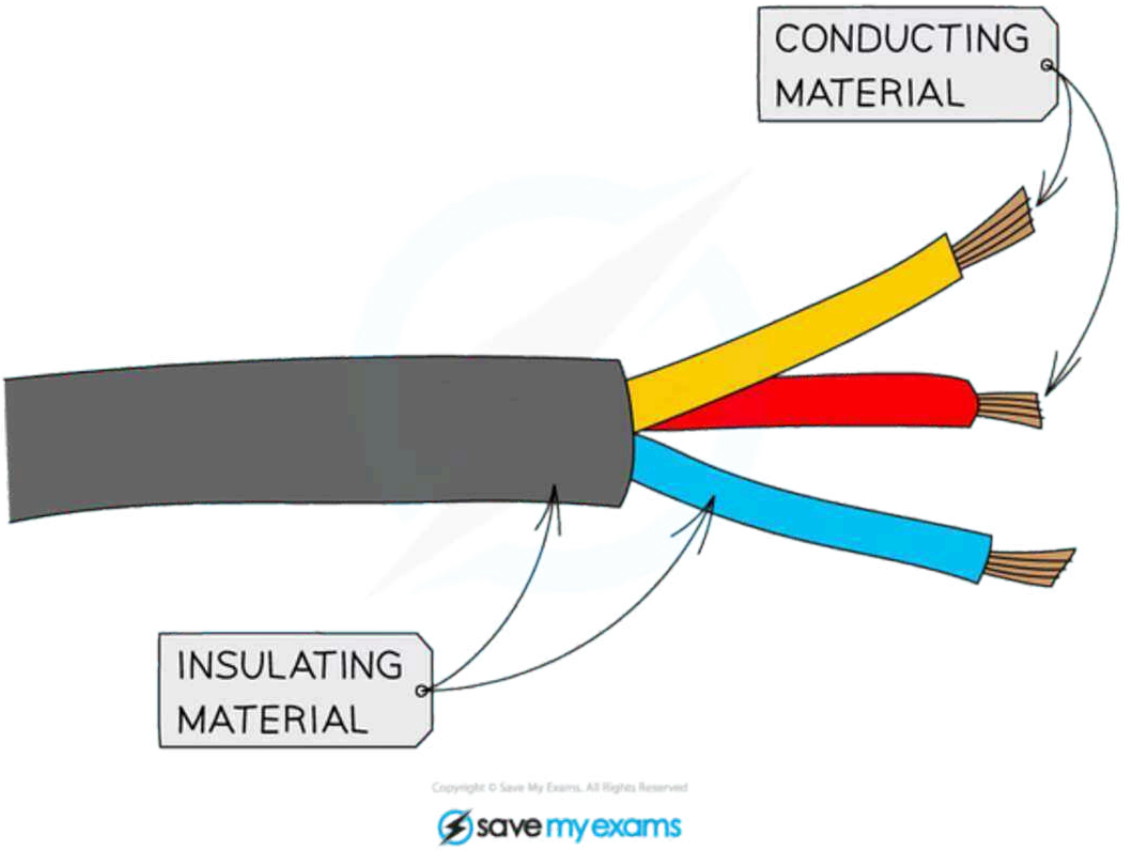
- The conducting part of a wire is usually made of copper or some other metal
 - If this comes into contact with a person, this poses a risk of electrocution
- For this reason, wires are covered with an insulating material, such as rubber

Insulated Wires

Your notes

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Your notes



The conducting part of a wire is covered in an insulating material for safety

- Some appliances do not have metal cases and so there is no risk of them becoming electrified
- Such appliances are said to be **double insulated**, as they have two layers of insulation:
 - Insulation around the wires themselves
 - A non-metallic case that acts as a second layer of insulation
- Double insulated appliances do not require an earth wire or have been designed so that the earth wire cannot touch the metal casing

Earthing

- Many electrical appliances have metal cases
- This poses a potential safety hazard:
 - If a live wire (inside the appliance) came into contact with the case, the case would become electrified and anyone who touched it would risk being electrocuted

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- The earth wire is an additional safety wire that can reduce this risk
- If this happens:
 - The earth wire provides a **low resistance path to the earth**
 - It causes a **surge of current in the earth wire** and hence also in the live wire
 - The high current through the fuse causes it to **melt and break**
 - **This cuts off the supply of electricity to the appliance**, making it safe


Your notes

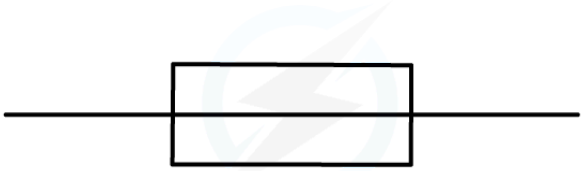
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Fuses & Trip Switches

Your notes

- A fuse is a safety device designed to **cut off the flow of electricity to an appliance if the current becomes too large** (due to a fault or a surge)

Circuit Symbol for a Fuse



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The circuit symbol for a fuse - take care not to confuse this with a resistor. The wire runs straight through the rectangle representing the fuse wire

- Fuses usually consist of a glass cylinder which contains a thin metal wire.
- If the current in the wire becomes too large:
 - The wire heats up and melts
 - This causes the wire to break, breaking the circuit and stopping the current
- A **trip switch,** found in the Consumer Box (where the electricity enters the building) does the same job as a fuse
 - When the current is too high the switch 'trips' (automatically flicks to the off position)
 - This stops current flowing in that circuit

Choosing Which Fuse to Use

- **Fuses come in a variety of sizes** (typically 3A, 5A and 13A) - in order to select the right fuse for the job, you need to know how much current an appliance needs
- If you know the power of the appliance (along with mains voltage), the current can be calculated using the equation:

$$\text{current} = \frac{\text{power}}{\text{potential difference}}$$

$$I = \frac{P}{V}$$

- The fuse should always have a current rating that is higher than the current needed by the appliance, without being too high - **always choose the next size up**

Example:

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- Suppose an appliance uses 3.1 amps
 - A 3 amp use would be too small - the fuse would blow as soon as the appliance was switched on
 - A 13 amp fuse would be too large - it would allow an extra 10 amps to pass through the appliance before it finally blew
 - A 5 amp fuse would be an appropriate choice, as it is the next size up


Your notes

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Electrical Energy


Your notes

Electrical Energy Equation

- Everyday appliances transfer electrical energy from the mains to other forms of energy in the appliance
 - For example, in a heater, this will transfer **electrical energy** into a **thermal energy store**
- The amount of energy an appliance transfers depends on:
 - How **long** the appliance is switched on for
 - The **power** of the appliance
- A 1 kW iron uses the **same** amount of energy in 1 hour as a 2 kW iron would use in 30 minutes
- A 100 W heater uses the **same** amount of energy in 30 hours as a 3000 W heater does in 1 hour

Calculating Electrical Energy

- To calculate electrical energy use the equation

$$E = VIt$$

- Where:
 - E = energy (joules, J)
 - V = voltage (volts, V)
 - I = current (amps, A)
 - t = time (seconds, s)

Exam Tip

Remember that kilo (k) means 1000, so 1 kW = 1000 W

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Electrical Power

Your notes

Electrical Power Equation

- In mechanics, power *P* is defined as the **rate of doing work**
 - The potential difference is the **work done per unit charge**
 - Current is the **rate of flow of charge**
- Therefore, the electrical power is defined as the **rate of change of work done**:

$$P = \frac{E}{t} = \frac{W}{t}$$

- Where:
 - *P* = power in watts (W)
 - *E* = energy in joules (J)
 - *t* = time in seconds (s)
 - *W* = work done in (J)
- The work done is the energy transferred so the power is the **energy transferred per second** in an electrical component
- The power dissipated (produced) by an electrical device can also be written as

$$P = IV$$

- Where:
 - *P* = power in watts (W)
 - *I* = current in amps (A)
 - *V* = potential difference in volts (V)
- Using Ohm's Law ***V = IR*** to rearrange for either *V* or *I* and substituting into the power equation, means power can be written in terms of resistance *R*

$$P = I^2R$$

$$P = \frac{V^2}{R}$$

- Where:
 - *P* = power in watts (W)
 - *I* = current in amps (A)
 - *R* = resistance in ohms (Ω)
 - *V* = potential difference in volts (V)

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- This means for a given resistor if the current or voltage **doubles** the power will be **four** times as great.
 - Which equation to use will depend on whether the value of current or voltage has been given in the question
- Rearranging the energy and power equation, the energy can be written as:

$$E = VIt$$

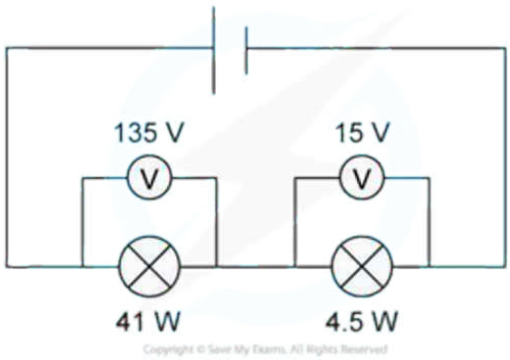
- Where:
 - E = energy transferred in joules (J)
 - V = potential difference in volts (V)
 - I = current in amps (A)
 - t = time in seconds (s)


Your notes

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Worked example

Two lamps are connected in series to a 150 V power supply.



Which statement most accurately describes what happens?

A. Both lamps light normally

B. The 15 V lamp blows

C. Only the 41 W lamp lights

D. Both lamps light at less than their normal brightness

Answer: A

- Calculate the current needed for both lamps to operate

$$P = IV$$

$$I = \frac{P}{V}$$

 - For the 41 W lamp:

$$I = \frac{41}{135} = 0.3 \text{ A}$$

 - For the 4.5 W lamp

$$I = \frac{4.5}{15} = 0.3 \text{ A}$$

- For both lamps to operate at their normal brightness, a current of 0.3 A is required

Your notes

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- Since the lamps are connected in series, the same current would flow through both
- Therefore, the lamps will light at their normal brightness
 - This is option **A**


Your notes

Exam Tip

You can use the mnemonic "Twinkle Twinkle Little Star, Power equals *I* squared *R*" to remember whether to multiply or divide by resistance in the power equations.

When doing calculations involving electrical power, remember the unit is Watts W, therefore, you should **always** make sure that the time is in **seconds**

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Measuring Energy Usage

The Kilowatt Hour (kWh)

Your notes

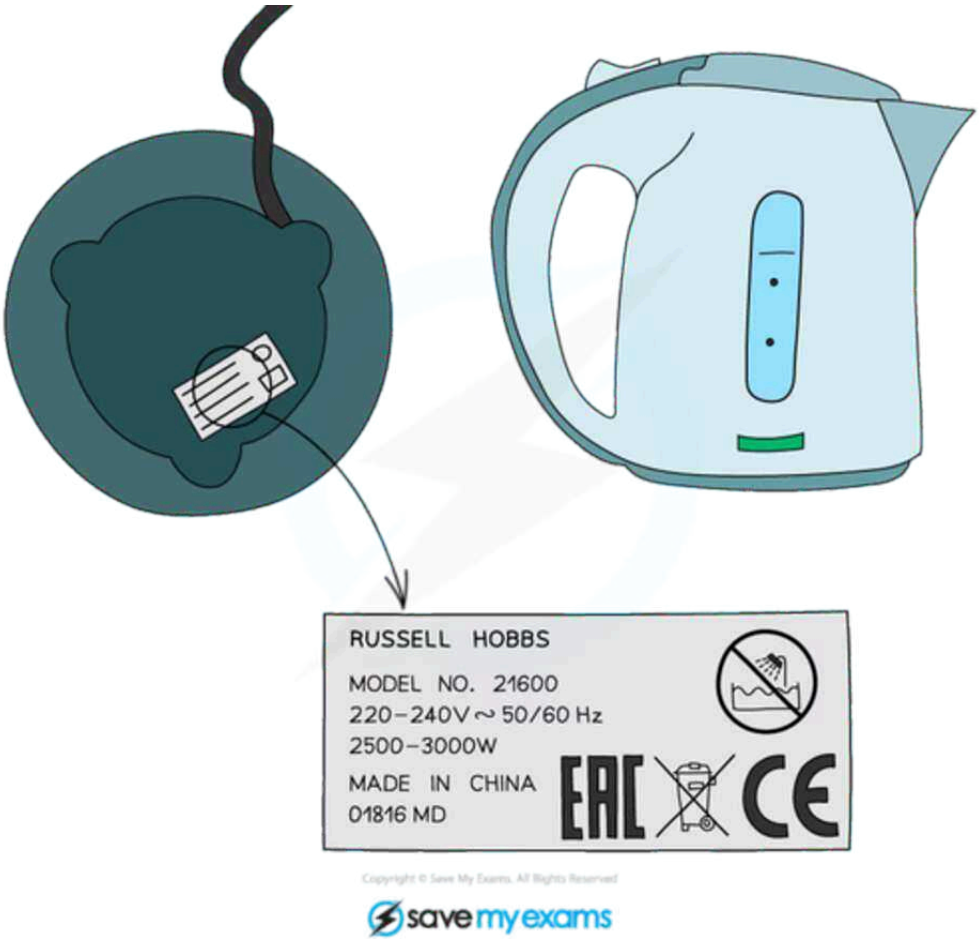
- Energy usage in homes and businesses is calculated and compared using the kilowatt hour
- The kilowatt hour is defined as:

A unit of energy equivalent to one kilowatt of power expended for one hour

- Appliances are given power ratings, which tell consumers:

The amount of energy transferred (by electrical work) to the device every second

Power Rating for a Kettle



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This kettle uses between 2500 and 3000 W of electrical energy

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- This energy is commonly measured in **kilowatt-hour (kW h)**, which is then used to calculate the cost of energy used


Your notes

Calculating with kWh

- The kilowatt hour can also be defined using an equation:

$$E = Pt$$

- Where
 - E = energy (kWh)
 - P = power (kW)
 - t = time (h)
 - This equation is unusual because **S.I. unit are not used**, both energy and power are **× 10^3**, and time is in **hours**, not seconds

- Since the usual unit of energy is joules (J), this is the **1 W in 1 s**
 - Therefore:

$$1\ \text{kW h} = 1000\ \text{W} \times 3600\ \text{s} = 3.6 \times 10^6\ \text{J}$$

 - Since 1 kW = 1000 W and 1 h = 3600 s

- To convert between Joules and kW h:

$$\text{kW h} \times (3.6 \times 10^6) = \text{J}$$

$$\text{J} \div (3.6 \times 10^6) = \text{kW h}$$

- The kW h is a large unit of energy, and mostly used for energy in homes, businesses, factories and so on

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Worked example

A cooker transfers 1.2×10^9 J of electrical energy to heat up a meal.

Calculate the cost of cooking the meal if 1 kW h costs 14.2p

Answer:

Step 1: Convert from J to kW h

$$(1.2 \times 10^9) \div (3.6 \times 10^6) = 333.333 \text{ kW h}$$

Step 2: Calculate the price

$$1 \text{ kW h} = 14.2 \text{ p}$$

$$333.333 \times 14.2 = 4733 \text{ p} = £47.33$$

Your notes

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Cambridge O Level Physics

Your notes

4.5 Electromagnetic Effects

Contents

- Electromagnetic Induction
- Demonstrating Induction
- The A.C. Generator
- Magnetic Effect of a Current
- Force on a Current-Carrying Conductor
- Fields Around Parallel Conductors
- Electric Motors
- Transformers
- Transformer Calculations

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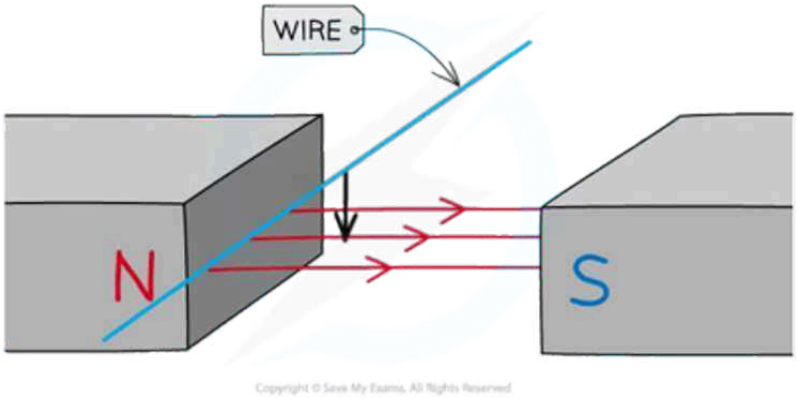
Electromagnetic Induction

Your notes

Induced EMF & Lenz's Law

- An EMF will be induced in a conductor if there is **relative movement** between the conductor and the magnetic field
- It will also be induced if the conductor is stationary in a changing magnetic field
- For an electrical conductor moving in a fixed magnetic field
 - The conductor (e.g wire) **cuts** through the fields lines
 - This **induces an EMF** in the wire

Current-Carrying Wire Moving Through a Magnetic Field

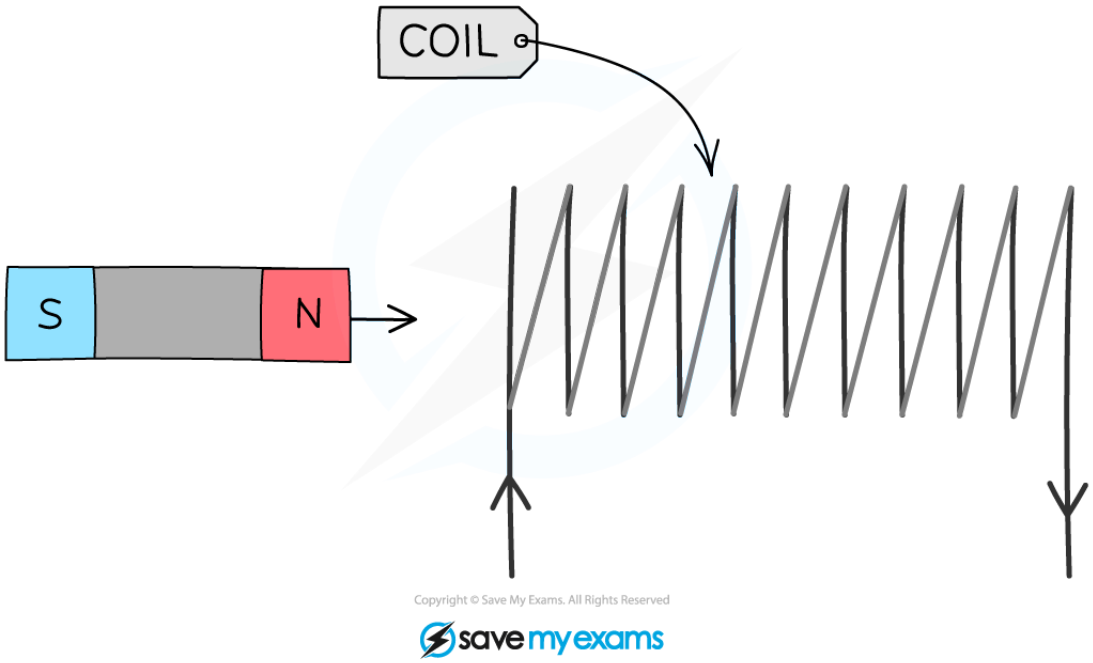


Moving an electrical conductor in a magnetic field to induce an EMF

Bar Magnet Moving Through a Solenoid

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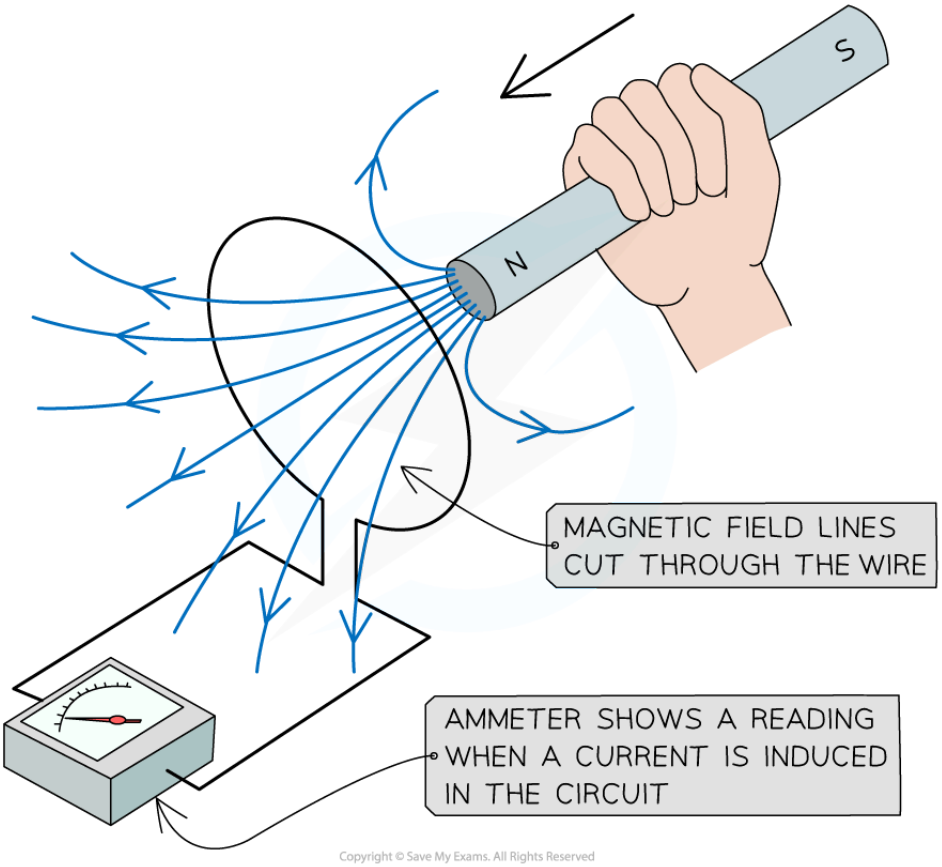
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When the magnet enters the coil, the field lines cut through the turns, inducing an EMF

- For a fixed conductor in a changing magnetic filed
 - As the magnet moved through the conductor (e.g. a coil), the field lines **cut** through the turns on the conductor (each individual wire)
 - This **induces an EMF** in the coil

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A magnet moved towards a wire creates a changing magnetic field and induces a current in the wire

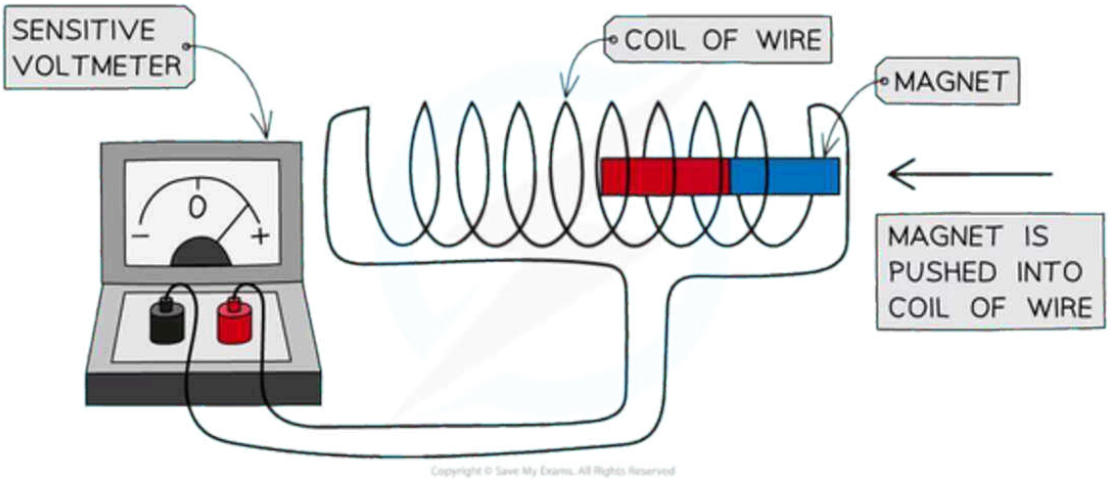
- A **sensitive voltmeter** can be used to measure the size of the induced EMF
- If the conductor is part of a **complete circuit** then a **current** is induced in the conductor
 - This can be detected by an ammeter

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Your notes

Worked example

A coil of wire is connected to a sensitive voltmeter. When a magnet is pushed into the coil the needle on the voltmeter will deflect to the right as shown in the diagram below.



What will happen to the pointer on the voltmeter when the magnet is stationary in the centre of the coil?

A The needle will deflect to the left

B The needle will deflect to the right

C There will be no deflection of the needle

D The needle will deflect to the left and then to the right

Answer: C

- **C** is correct because there the magnet is stationary
- This means there is no relative movement between the coil and the magnetic field, therefore there are no magnetic field lines being cut
- If the magnetic field lines are not being cut then there will not be a potential difference induced
- **A**, **B** & **D** are incorrect because a deflection on the voltmeter would indicate that a potential difference has been induced
- This could only happen if there was relative movement between the coil and the magnetic field

Lenz's Law

- Lenz Law states:

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The direction of an induced potential difference always opposes the change that produces it

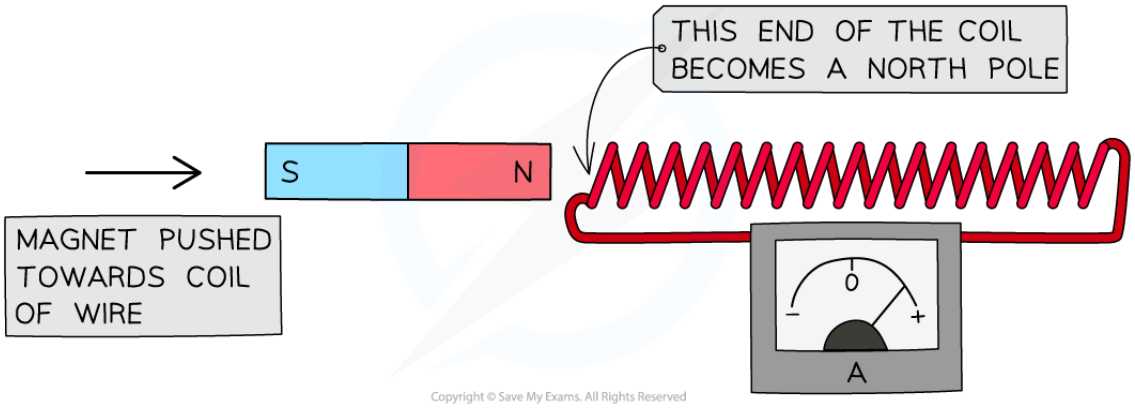
Your notes

- This means that any magnetic field created by the potential difference will act so that it tries to stop the wire or magnet from moving

Demonstrating Lenz's Law

- If a magnet is pushed north end first into a coil of wire then the end of the coil closest to the magnet will become a **north pole**
- Explanation
 - Due to the generator effect, a **potential difference** will be induced in the coil
 - The induced potential difference always **opposes** the change that produces it
 - The coil will apply a **force** to oppose the magnet being pushed into the coil
 - Therefore, the end of the coil closest to the magnet will become a **north pole**
 - This means it will **repel** the north pole of the magnet

Bar Magnet Approaching a Solenoid



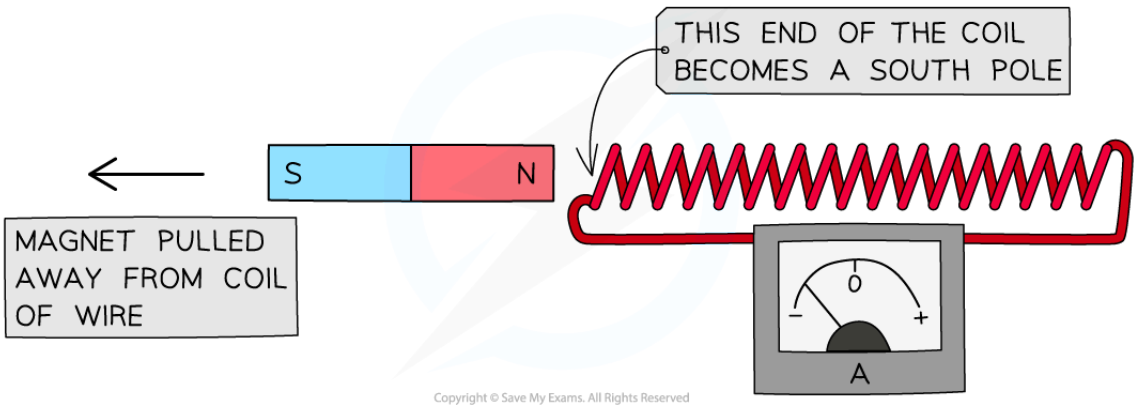
Magnet being pushed into a coil of wire inducing a current in the wire

- If a magnet is now pulled away from the coil of wire then the end of the coil closest to the magnet will become a **south pole**
- Explanation:
 - Due to the generator effect, a **potential difference** will be induced in the coil
 - The induced potential difference always **opposes** the change that produces it
 - The coil will apply a **force** to oppose the magnet being pulled away from the coil
 - Therefore, the end of the coil closest to the magnet will become a **south pole**
 - This means it will **attract** the north pole of the magnet

Bar Magnet Leaving Solenoid

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Your notes



Magnet being pulled away from a coil of wire due to force of attraction

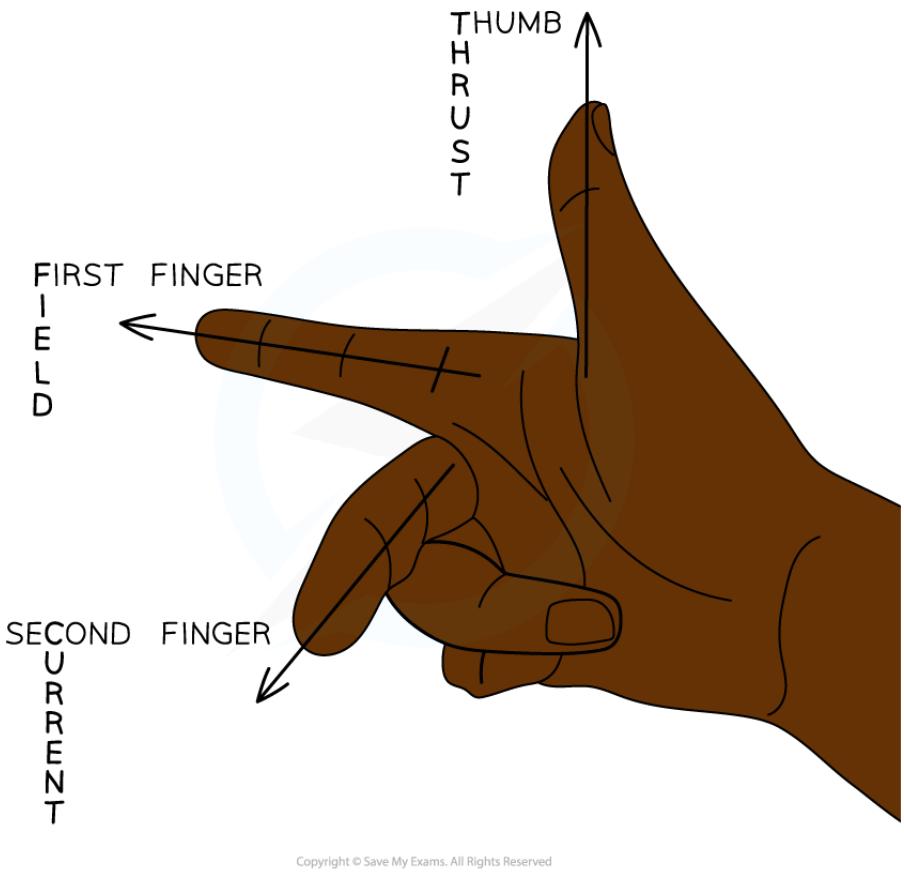
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Right-Hand Dynamo Rule

Your notes

- When moving a wire through a magnetic field, the direction of the induced EMF can be worked out by using the **Right-Hand Dynamo** rule

Right-Hand Dynamo Rule



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The Right-Hand Dynamo rule can be used to deduce the direction of the induced EMF

- To use the rule:
 First **F**inger = **F**ield:
 - Start by pointing the **f**irst **f**inger (on the right hand) in the direction of the **f**ield

 Thu**M**b = **M**otion:
 - Next, point the thu**m**b in the direction that the wire is **m**oving in

 Se**C**ond = **C**urrent:

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- The Second finger will now be pointing in the direction of the **c**urrent (or, strictly speaking, the EMF)
- The direction of the induced EMF always **opposes the change that produces it**
 - This means that any magnetic field created by the EMF will act so that it tries to stop the wire or magnet from moving


Your notes

Exam Tip

Remember that current is always in the direction of positive charge carriers. Therefore, current flows from the positive to the negative terminal of the battery.

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Demonstrating Induction

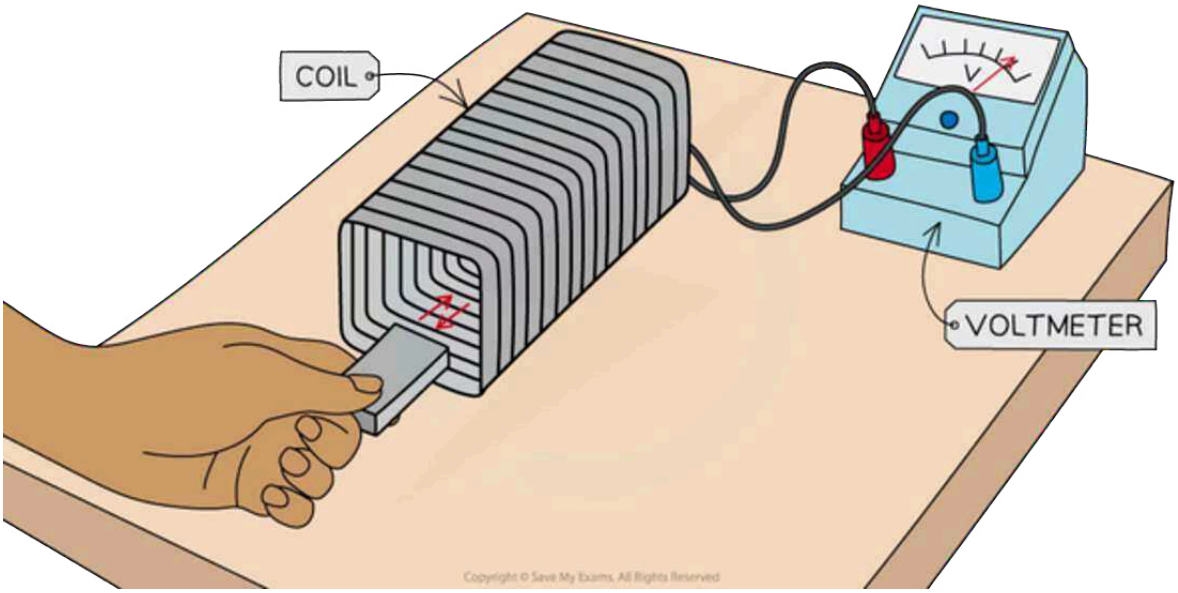
Your notes

Demonstrating Induction

- An EMF can be induced either when:
 - A conductor, such as a wire, cuts through a magnetic field
 - The direction of a magnetic field through a coil changes
- Electromagnetic induction is used in:
 - Electrical generators which convert mechanical energy to electrical energy
 - Transformers which are used in electrical power transmission
- This phenomenon can easily be demonstrated with a magnet and a coil

Experiment 1: Moving a magnet through a coil

- When a coil is connected to a sensitive voltmeter, a bar magnet can be moved in and out of the coil to induce an EMF



A bar magnet is moved through a coil connected to a voltmeter to induce an EMF

The expected results are:

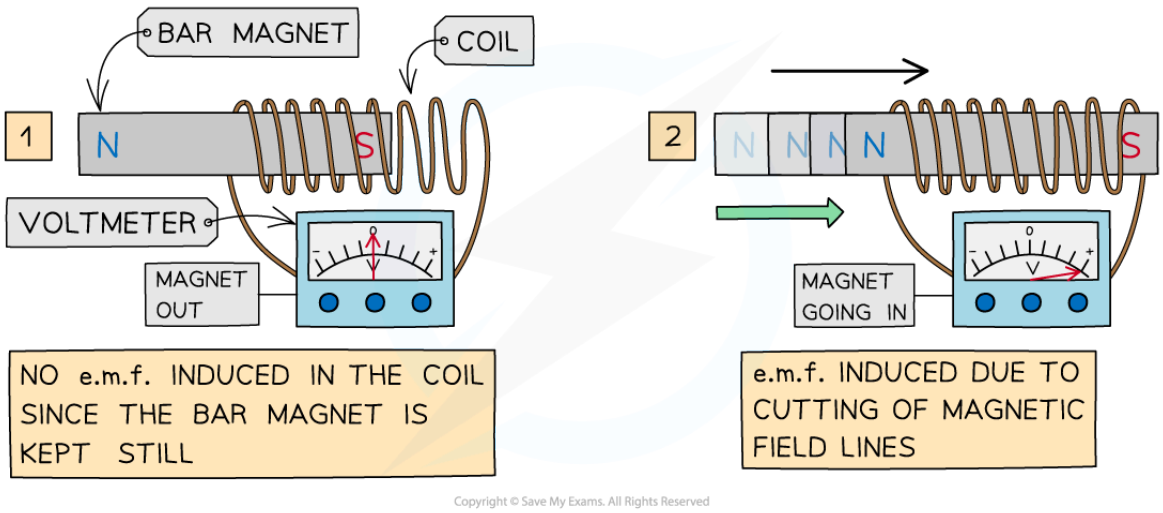
- When the bar magnet is **not moving**, the voltmeter shows a **zero reading**

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Your notes

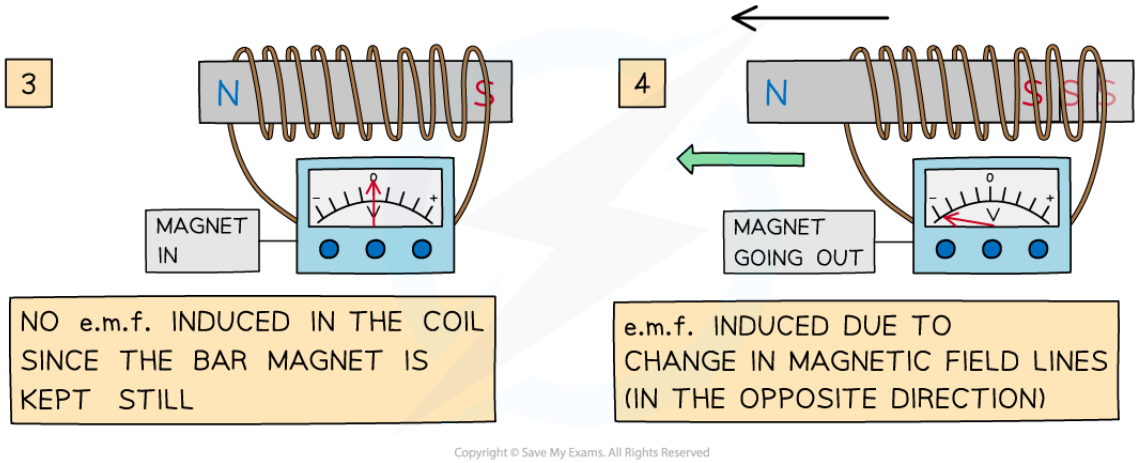
- When the bar magnet is held still inside, or outside, the coil, there is no cutting of magnetic field lines, so, there is **no EMF induced**
- When the bar magnet begins to move inside the coil, there is a reading on the voltmeter
 - As the bar magnet moves, its magnetic field lines 'cut through' the coil
 - This induces an **EMF** within the coil, shown momentarily by the reading on the voltmeter
- When the bar magnet is taken back out of the coil, an e.m.f is induced in the **opposite direction** (a result of Lenz's law)
 - As the magnet changes direction, the direction of the current changes
 - The voltmeter will momentarily show a reading with the opposite sign
- Increasing the **speed** of the magnet induces an e.m.f with a **higher magnitude**
- The direction of the electric current, and e.m.f, induced in the conductor is such that it **opposes** the change that produces it
 - This is Lenz's law

Lenz's Law



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An e.m.f is induced only when the bar magnet is moving through the coil

- Factors that will increase the induced EMF are:
 - Moving the magnet **faster** through the coil
 - Adding **more turns** to the coil
 - Increasing the **strength** of the bar magnet

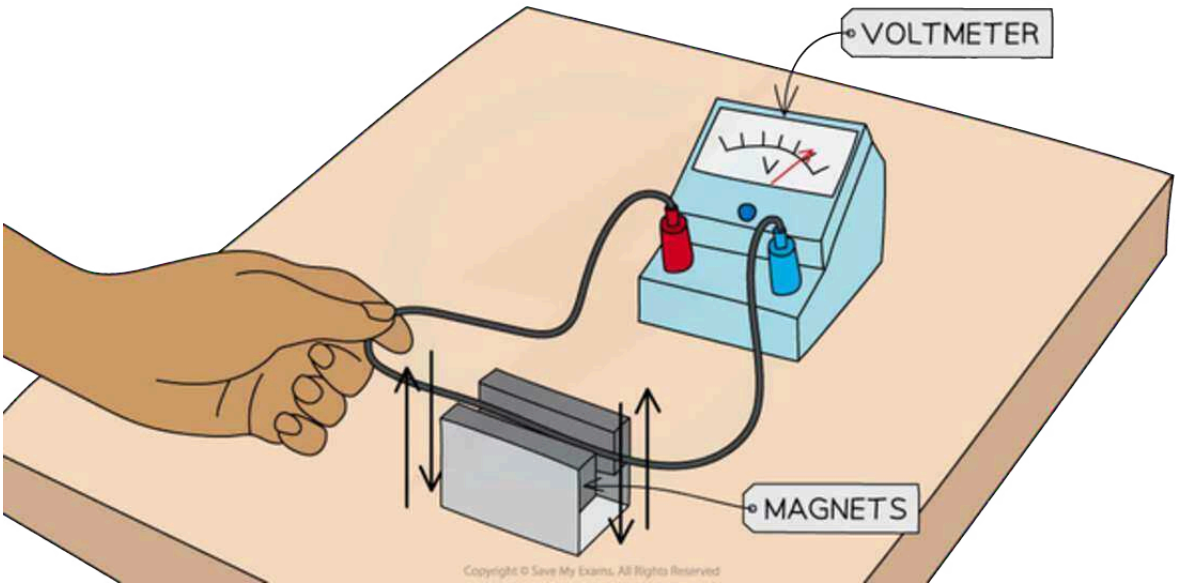
Experiment 2: Moving a wire through a magnet

- When a long wire is connected to a voltmeter and moved between two magnets, an EMF is induced
- The pattern of a magnetic field in a wire can be investigated using this set up
 - **Note:** there is no current flowing through the wire to start with

Your notes

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Your notes



A wire is moved between two magnets connected to a voltmeter to induce an EMF

The expected results are:

- When the wire is **not moving**, the voltmeter shows a **zero reading**
 - When the wire is held still inside, or outside, the magnets, the rate of change of flux is zero, so, there is **no EMF induced**
- As the wire is moved through between the magnets, an **EMF** is induced within the wire, shown momentarily by the reading on the voltmeter
 - As the wire moves, it 'cuts through' the magnetic field lines of the magnet, generating a **change in magnetic flux**
- When the wire is taken back out of the magnet, an EMF is induced in the **opposite direction**
 - As the wire changes direction, the direction of the current changes
 - The voltmeter will momentarily show a reading with the opposite sign
- As before, the direction of the electric current, and e.m.f, induced in the conductor is such that it **opposes** the change that produces it
- Factors that will increase the induced e.m.f are:
 - Increasing the **length** of the wire
 - Moving the wire between the magnets **faster**
 - Increasing the **strength** of the magnets

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Factors Affecting EM Induction


Your notes

- The magnitude (size) of the induced EMF is determined by:
 - The **speed** at which the wire, coil or magnet is moved
 - The **number of turns** on the coils of wire
 - The **size** of the coils
 - The **strength** of the magnetic field
- The **direction** of the induced potential difference is determined by:
 - The **orientation** of the poles of the magnet

1. The **speed** at which the wire, coil or magnet is moved:

- **Increasing the speed** will increase the rate at which the magnetic field lines are cut
- This will **increase the induced potential difference**

2. The **number** of turns on the coils in the wire:

- **Increasing the number of turns on the coils** in the wire will **increase the potential difference** induced
- This is because each coil will cut through the magnetic field lines and the total potential difference induced will be the result of all of the coils cutting the magnetic field lines

3. The **size** of the coils:

- **Increasing the area** of the coils will **increase the potential difference** induced
- This is because there will be more wire to cut through the magnetic field lines

4. The **strength** of the magnetic field:

- Increasing the **strength** of the magnetic field will **increase** the **potential difference induced**

5. The **orientation** of the poles of the magnet:

- Reversing the direction in which the wire, coil or magnet is moved

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Exam Tip

When discussing factors affecting the induced potential difference:

- Make sure you state:
 - "Add more **turns** to the coil" instead of "Add more coils"
 - This is because these statements do not mean the same thing
- Likewise, when referring to the magnet, use the phrase:
 - "**A stronger magnet** instead of "A bigger magnet"
 - This is because larger magnets are not necessarily stronger



Your notes

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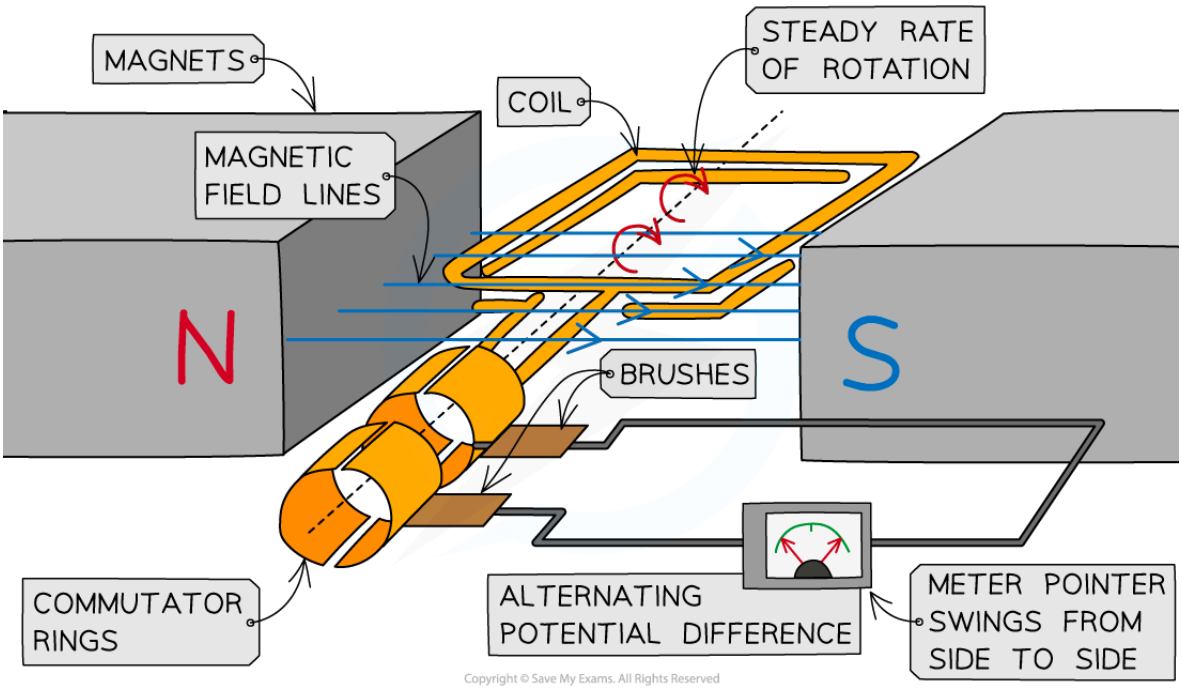
The A.C. Generator

Your notes

Simple A.C Generators

- The **generator effect** can be used to generate **a.c** in an **alternator**
- A simple alternator is a type of generator that converts mechanical energy to electrical energy in the form of alternating current

Structure of an Alternator



An alternator is a rotating coil in a magnetic field connected to slip rings

- A rectangular coil that is forced to spin in a **uniform magnetic field**
- The coil is connected to a centre-reading meter by **metal brushes** that press on two metal **slip rings**
 - The slip rings and brushes provide a connection between the coil and the meter
- When the coil turns in one direction:
 - The pointer defects first one way, then the opposite way, and then back again
 - This is because the coil **cuts through** the magnetic field lines and an **EMF,** and therefore current, is **induced** in the coil

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- The pointer deflects in both directions because the current in the circuit repeatedly **changes direction** as the coil spins
 - This is because the induced EMF in the coil repeatedly changes its direction
 - This continues on as long as the coil keeps turning in the **same** direction
- The induced EMF and the current **alternate** because they repeatedly **change direction**


Your notes

Exam Tip

Motors and generators look very similar, but they do very different things.

When tackling a question on either of them, make sure you are writing about the right one! A **mo**tor takes in electricity and turns it into **mo**tion. A **generator** takes in motion and **generates** electricity.

You might be expected to give explanations of how these two things happen - make sure that you understand their subtle differences!

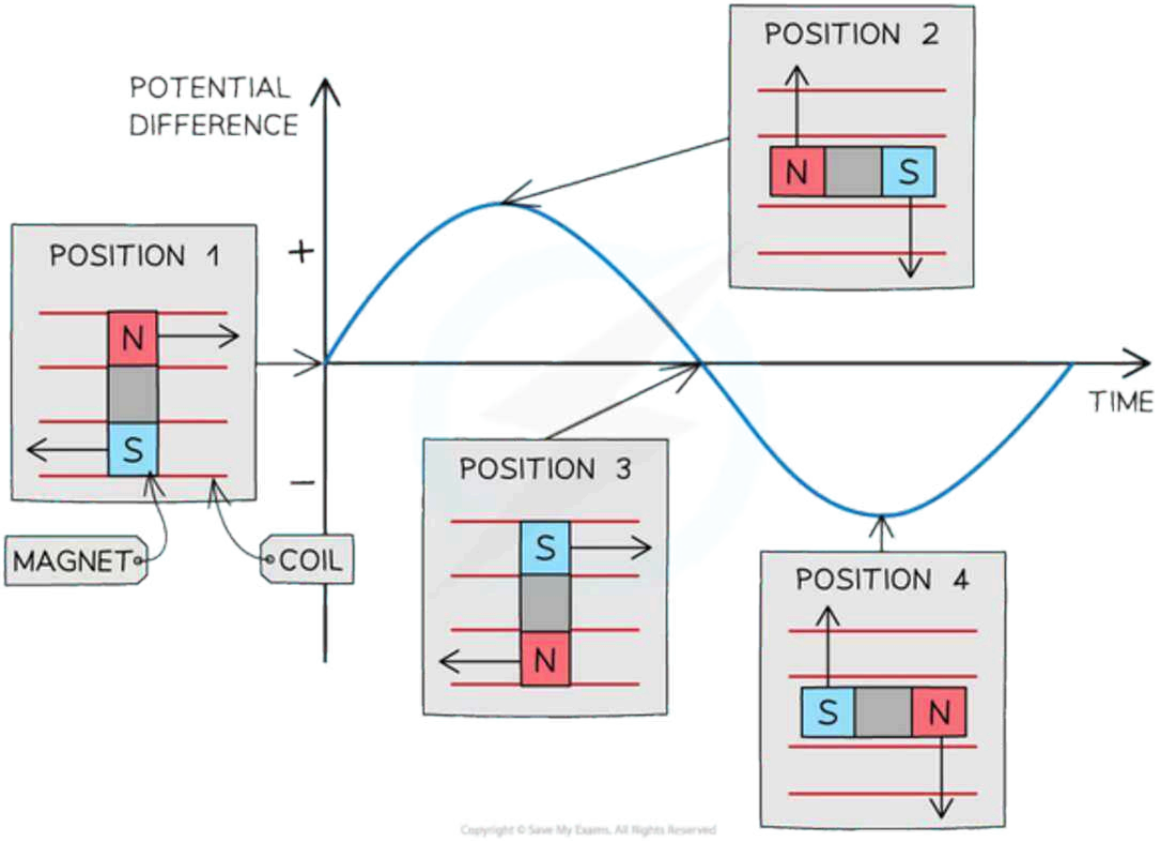
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Graphs for A.C. Generators

Your notes

- The A.C. generator creates an **alternating current**, varying in size and direction as the coil rotates
- The size of the induced EMF depends on the number of field lines it cuts
 - The induced EMF is greatest (maximum value) when the coil is **horizontal**, or parallel with the field lines, as in this position it cuts through the field at the fastest rate
 - The EMF is smallest (0) when the coil is **vertical**, or perpendicular with the field lines as in this position it will not be cutting through field lines

Graph for an A.C. Generator



Alternating EMF showing the position of the magnet relative to the coil

- When the magnet is in **position 1** the magnetic field lines of the magnet **do not cut the coil**
 - This means that there is **no EMF** induced in the coil
- When the magnet is in **position 2** the magnetic field lines of the magnet are at **90°** to the coil
 - This means that there will be **maximum** EMF induced in the coil

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- When the magnet is in **position 3** the magnetic field lines of the magnet **do not cut the coil**
 - This means that there is **no EMF** induced in the coil
- When the magnet is in **position 4** the magnetic field lines of the magnet are at **90°** to the coil
 - This means that there will be maximum EMF induced in the coil
 - As the **poles** of the magnet are **reversed** compared to position 2 the induced EMF will also be in the opposite direction compared to position 2
 - This means that the graph will show a **negative trace**


Your notes

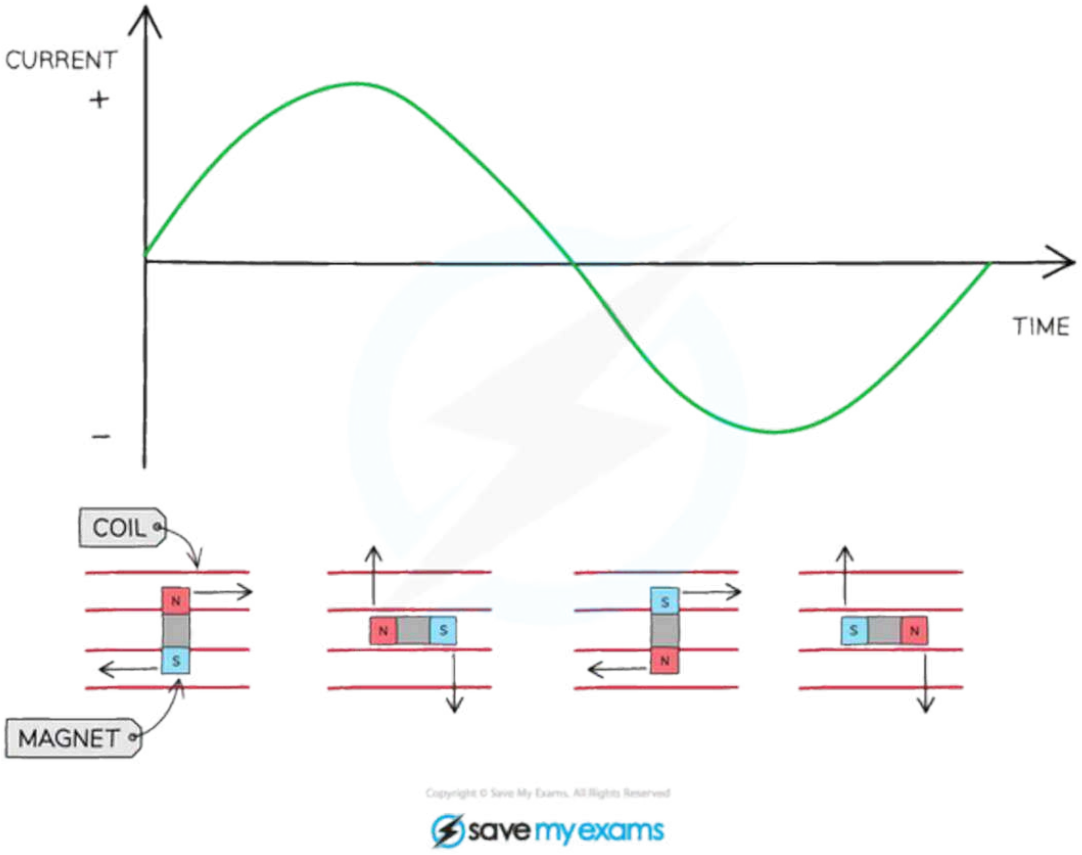
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Exam Tip

Make sure you can remember how the induced EMF relates to the number of field lines cut by the coil:

- When the plane of the coil is **perpendicular** to the field lines
 - When the number of field lines cut is at its **maximum**
 - Induced EMF = **0**
- When the plane of the coil is **parallel** to the field lines
 - When the number of field lines cut = **0**
 - Induced e.m.f is at its **maximum**

The A.C output from an alternator leads to a current which is both in the positive and negative region of the graph



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Your notes

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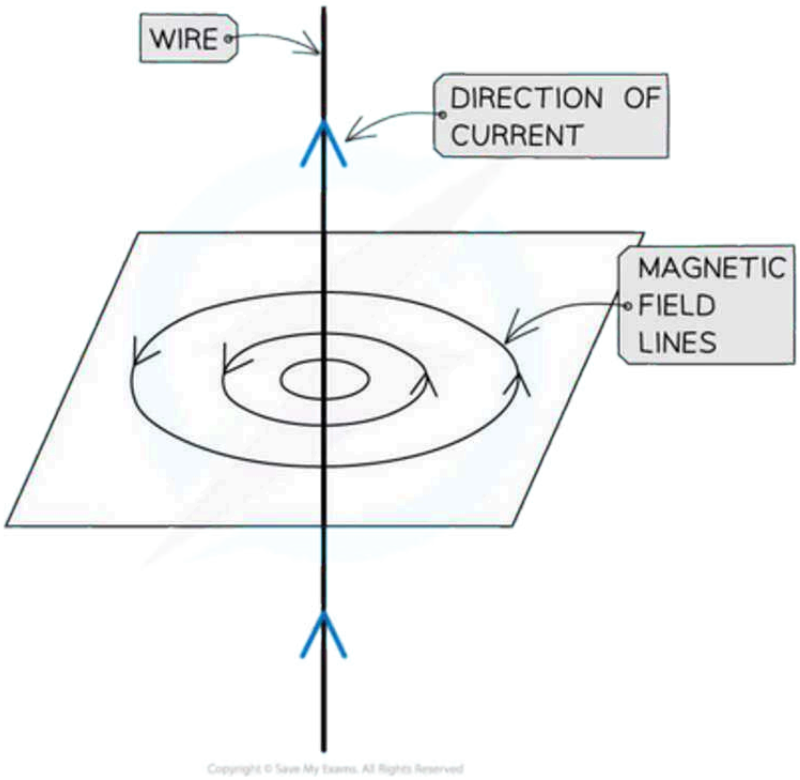
Magnetic Effect of a Current

Your notes

Magnetic Field Around Wires & Solenoids

- When a **current** flows through a conducting wire a **magnetic field** is produced around the wire
 - A conducting wire is any wire that has **current** flowing through it
- The shape and direction of the magnetic field can be investigated using plotting compasses
 - The compasses would produce a magnetic field lines pattern that would like look the following

Magnetic Field Around a Current-Carrying Wire



The magnetic field pattern around a current-carrying wire is a series of concentric circles

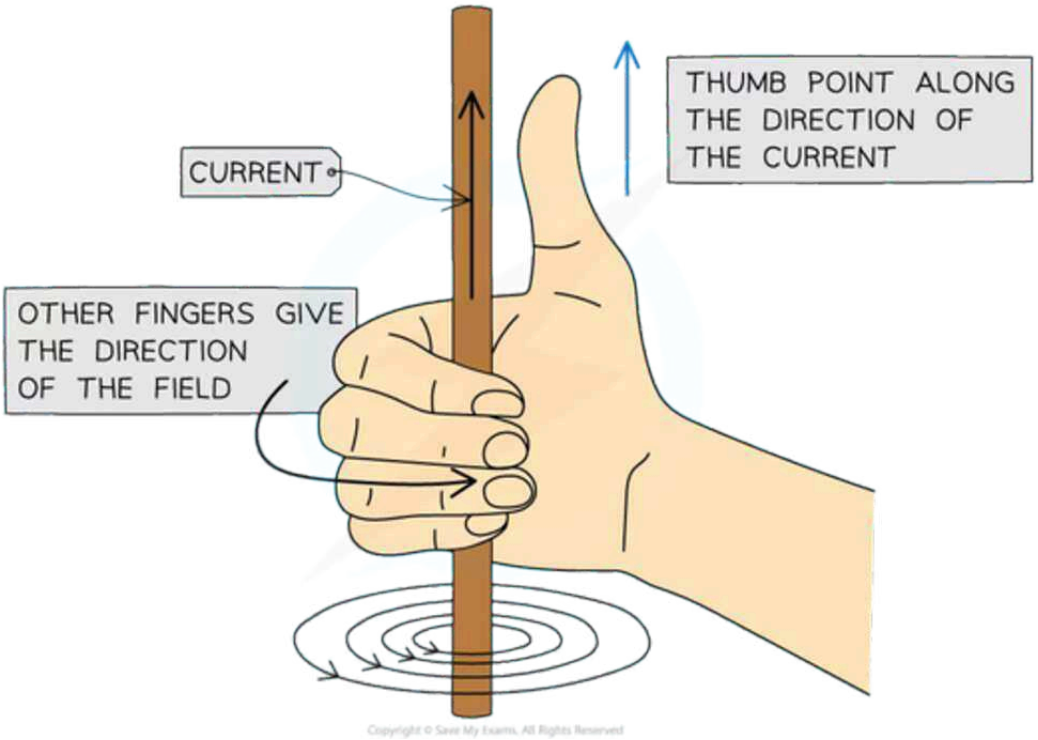
- The magnetic field is made up of **concentric circles**
 - A circular field pattern indicates that the magnetic field around a current-carrying wire has **no poles**
- As the distance from the wire increases the circles get further apart
 - This shows that the magnetic field is strongest closest to the wire and gets weaker as the distance from the wire increases

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Your notes

- The **right-hand thumb rule** can be used to work out the **direction** of the magnetic field

Right-Hand Thumb Rule



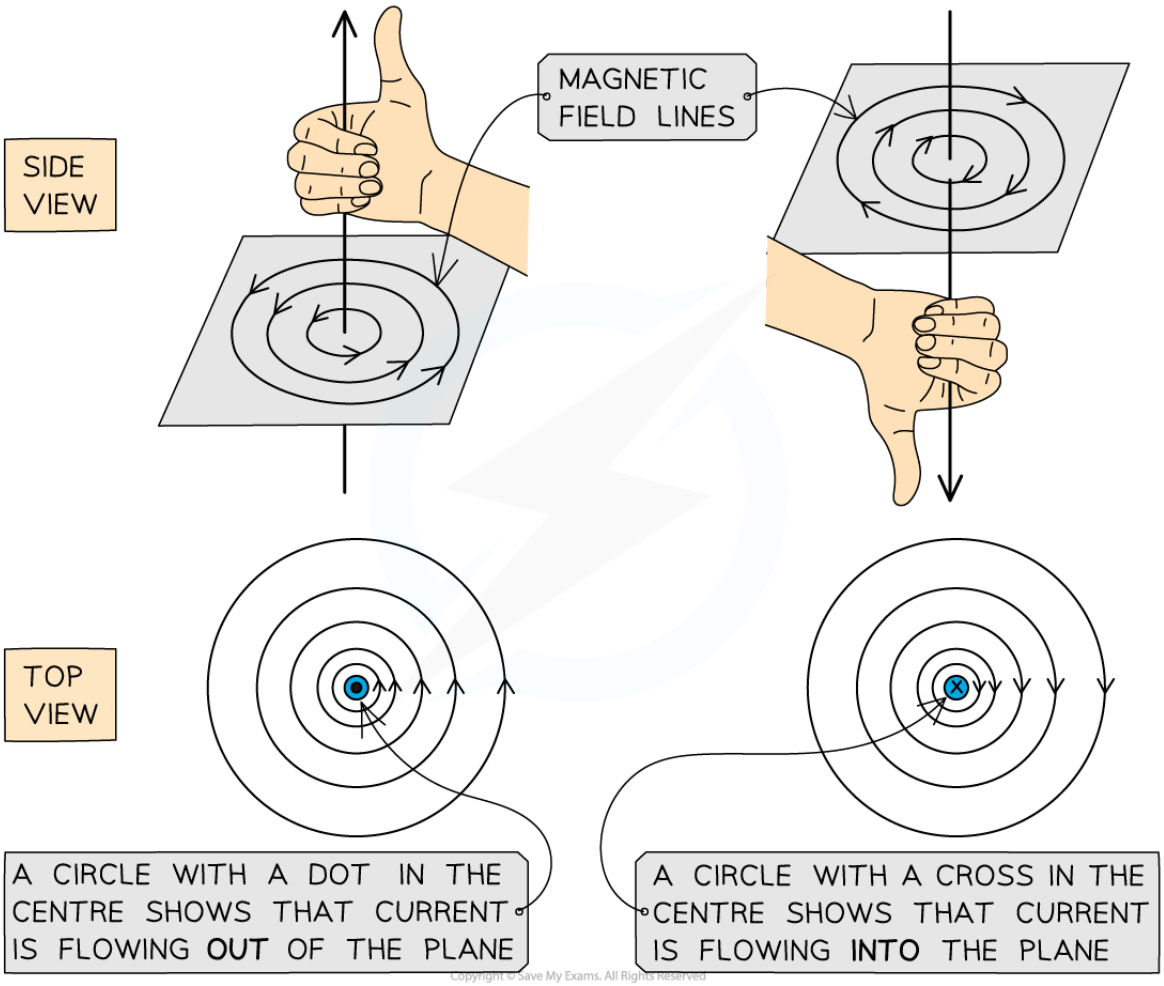
The right-hand thumb rule shows the direction of current flow through a wire and the direction of the magnetic field around the wire

- Reversing the direction in which the current flows through the wire will **reverse the direction** of the magnetic field

Different Views of Magnetic Field Lines Around a Current-Carrying Wire

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Your notes



Side and top view of the current flowing through a wire and the magnetic field produced

- If there is **no current** flowing through the conductor there will be **no magnetic field**
- Increasing the amount of current flowing through the wire will increase the strength of the magnetic field
 - This means the field lines will become **closer together**

Magnetic Field Around a Solenoid

- When a wire is looped into a **coil**, the magnetic field lines circle around each part of the coil, passing through the centre of it

Field Lines Around Loops of Wire

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Your notes

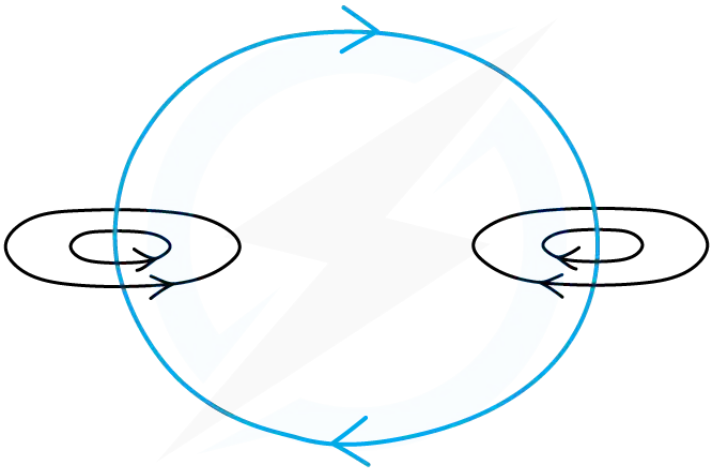
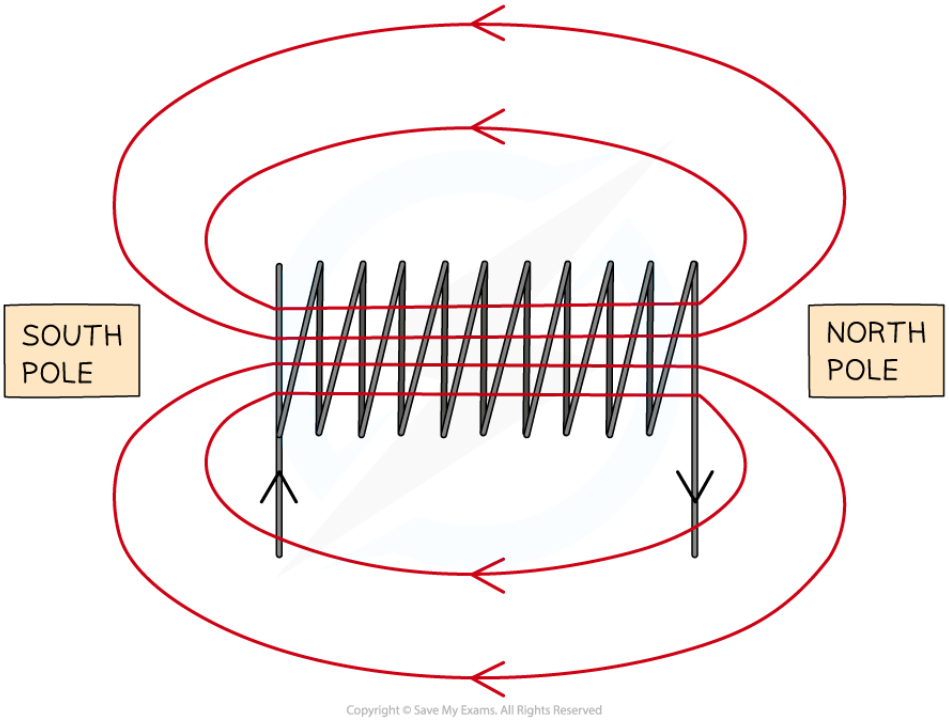

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Diagram showing the magnetic field around a flat circular coil

- To increase the strength of the magnetic field around the wire it should be coiled to form a **solenoid**
- The magnetic field around the solenoid is similar to that of a **bar magnet**

Magnetic Field Produced by a Solenoid



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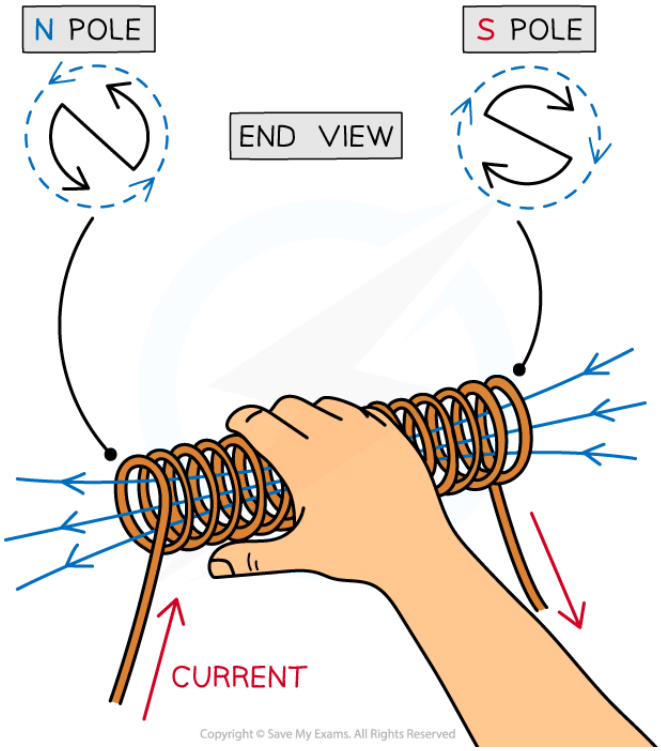
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Your notes

Magnetic field around and through a solenoid

- The magnetic field inside the solenoid is strong and uniform
- One end of the solenoid behaves like the **north pole** of a magnet; the other side behaves like the **south pole**
 - To work out the polarity of each end of the solenoid it needs to be viewed from the end
 - If the current is travelling around in a **clockwise** direction then it is the **south pole**
 - If the current is travelling around in an **anticlockwise** direction then it is the north pole
- If the **current changes direction** then the north and south **poles will be reversed**
- If there is **no current** flowing through the wire then there will be **no magnetic field** produced around or through the solenoid

Poles of a Solenoid



If the current is travelling in a clockwise direction around the end of the solenoid, the induced pole is a south pole and vice versa

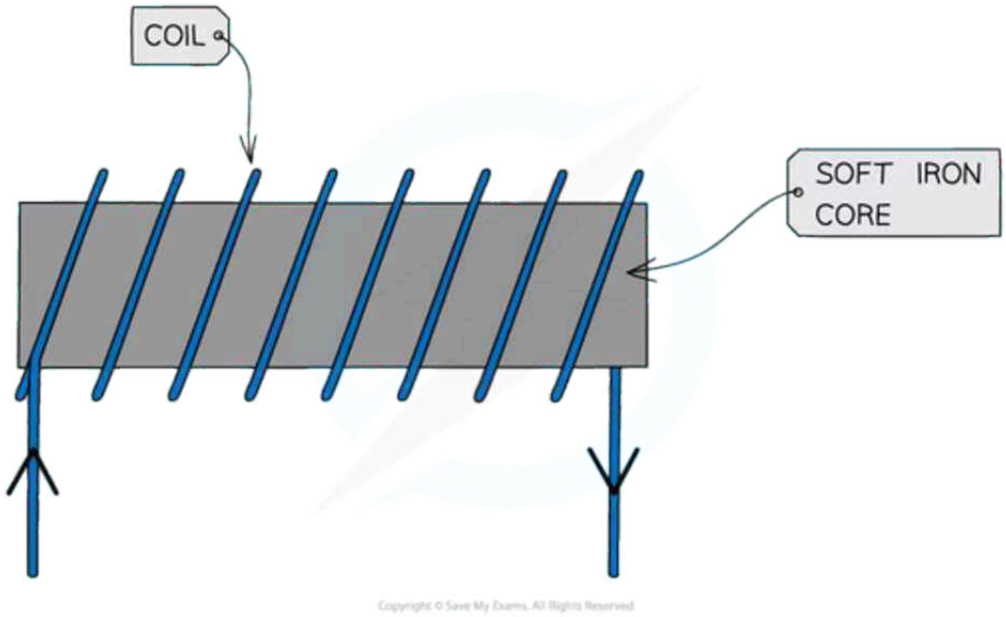
- A solenoid can be used as an electromagnet by adding a soft **iron core**
- The iron core will become an induced magnet when current is flowing through the coils
 - The magnetic field produced from the solenoid and the iron core will create a much **stronger** magnet overall

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Your notes

- The magnetic field produced by the electromagnet can be **switched on and off**
 - When the current is **flowing** there will be a magnetic field produced around the electromagnet
 - When the current is **switched off** there will be **no** magnetic field produced around the electromagnet

Structure of Electromagnet



An electromagnet consists of a solenoid wrapped around a soft iron core

- Changing the direction of the current also changes the direction of the magnetic field produced by the iron core

Factors Affecting Magnetic Field Strength

- The strength of the magnetic field produced around a **solenoid** can be increased by:
 - Increasing the **size of the current** which is flowing through the wire
 - Increasing the **number of coils**
 - Adding an **iron core** through the centre of the coils
- The strength of an **electromagnet** can be changed by:
 - Increasing the current will **increase** the magnetic field produced around the electromagnet
 - Decreasing the current will **decrease** the magnetic field produced around the electromagnet

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Exam Tip

When trying to figure out how an electromagnetic device works:

- Look for a coil / solenoid - this is going to act as an electromagnet
- Look for a piece of iron - this will be attracted to the solenoid

Your notes

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Applications of the Magnetic Effect

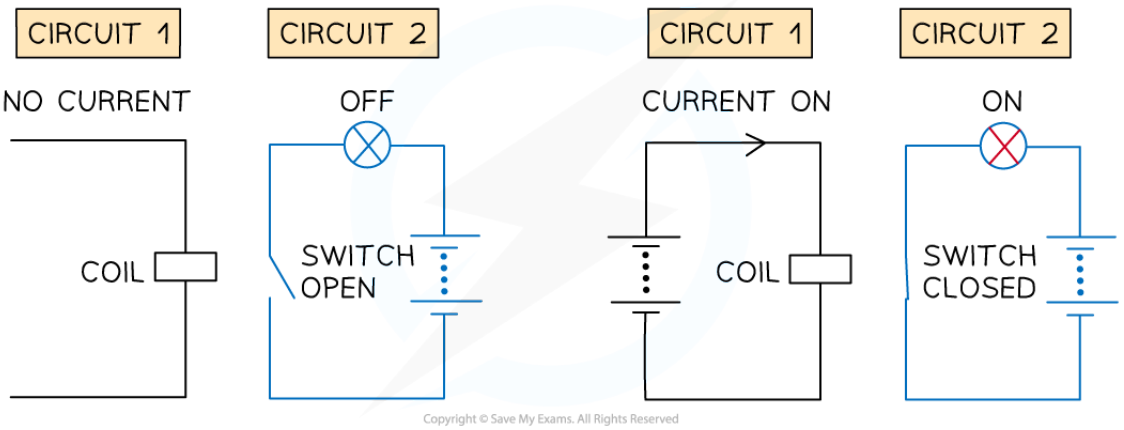
Your notes

- Electromagnets are used in a wide variety of applications, including:
 - **Relay circuits** (utilised in electric bells, electronic locks, scrapyard cranes etc)
 - **Loudspeakers & headphones**

Relay Circuits

- Electromagnets are commonly used in **relay circuits**
- Relays are switches that open and close via the action of an electromagnet
- A relay circuit consists of:
 - An electrical circuit containing an electromagnet
 - A second circuit with a switch which is near to the electromagnet in the first circuit

Relay Circuits



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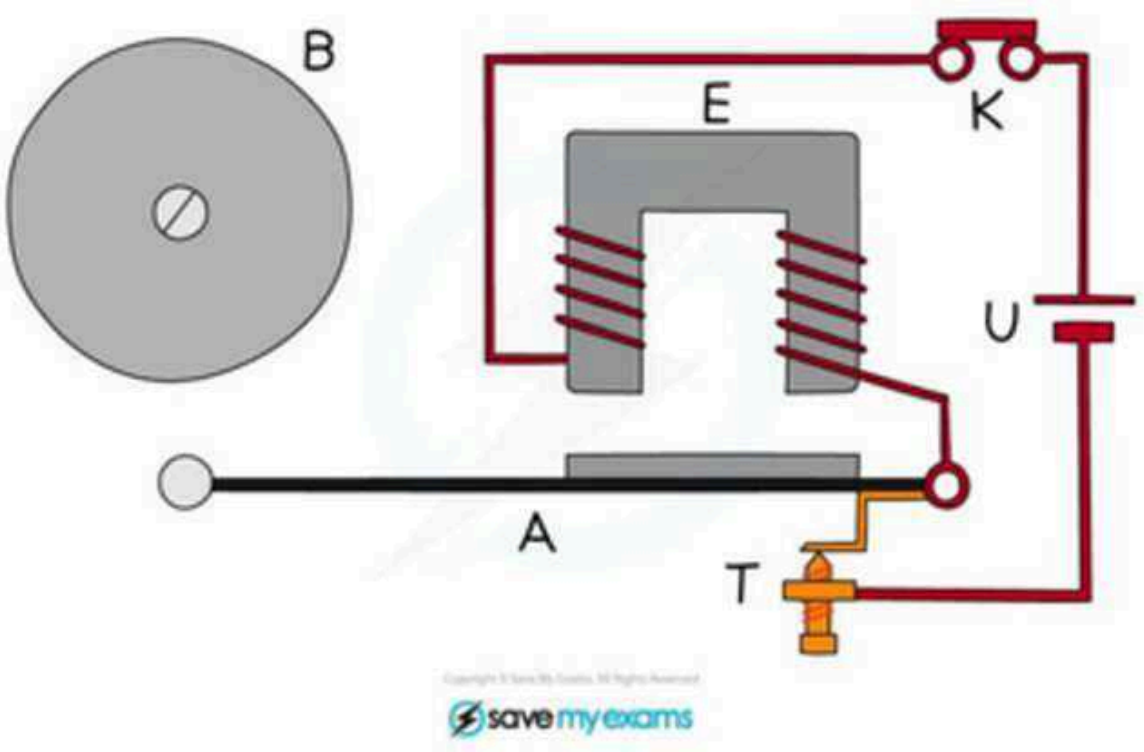
When a current passes through the coil in Circuit 1, it attracts the switch in Circuit 2, closing it enables a current to flow in Circuit 2

- When a current flows through **Circuit 1**, a magnetic field is induced around the coil
 - The magnetic field attracts the switch, causing it to pivot and close the contacts in **Circuit 2**
 - This allows a current to flow in **Circuit 2**
- When no current flows through **Circuit 1**, the magnetic force stops
 - The electromagnet stops attracting the switch
 - The current in **Circuit 2** stops flowing
- Scrapyard cranes utilise relay circuits to function:
 - When the electromagnet is switched on it will **attract** magnetic materials
 - When the electromagnet is switched off it will **drop** the magnetic materials
- Electric bells also utilise relay circuits to function

Electric Bell

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Your notes



Animation: Electric bells utilise relay circuits. As the current alternates, the metal arm strikes the bell and drops repeatedly to produce the ringing effect

- When the button **K** is pressed:
 - A current passes through the electromagnet **E** creating a magnetic field
 - This attracted the iron armature **A**, causing the hammer to strike the bell **B**
 - The movement of the armature breaks the circuit at **T**
 - This stops the current, destroying the magnetic field and so the armature returns to its previous position
 - This re-establishes the circuit, and the whole process starts again

Loudspeakers & Headphones

- Loudspeakers and headphones convert electrical signals into sound
 - They work due to the **motor effect**
- A loudspeaker consists of a **coil of wire** which is wrapped around one pole of a **permanent magnet**

Loud Speaker

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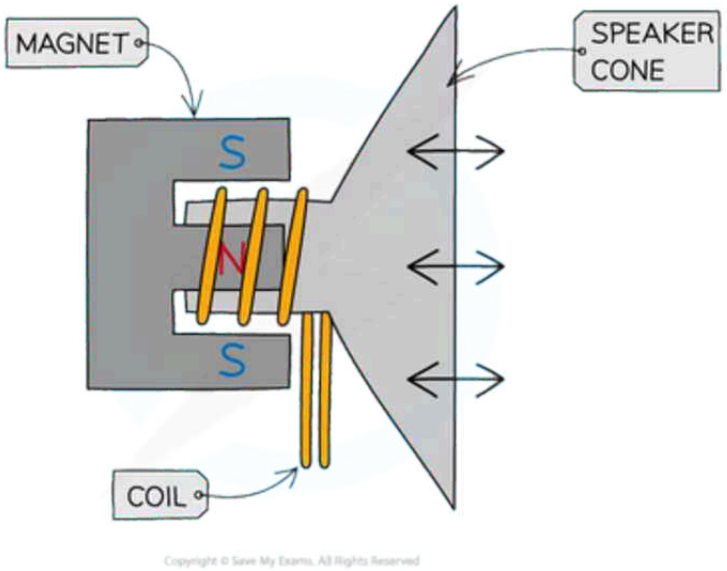


Diagram showing a cross-section of a loudspeaker

- An **alternating current** passes through the coil of the loudspeaker
 - This creates a **changing magnetic field** around the coil
- As the current is constantly changing direction, the direction of the magnetic field will be **constantly changing**
- The magnetic field produced around the coil **interacts** with the field from the permanent magnet
- The interacting magnetic fields will exert a **force** on the coil
 - The direction of the force at any instant can be determined using **Fleming's left-hand rule**
- As the magnetic field is constantly changing direction, the **force** exerted on the coil will **constantly change direction**
 - This makes the coil **oscillate**
- The oscillating coil causes the speaker cone to oscillate
 - This makes the air oscillate, creating **sound waves**

Your notes

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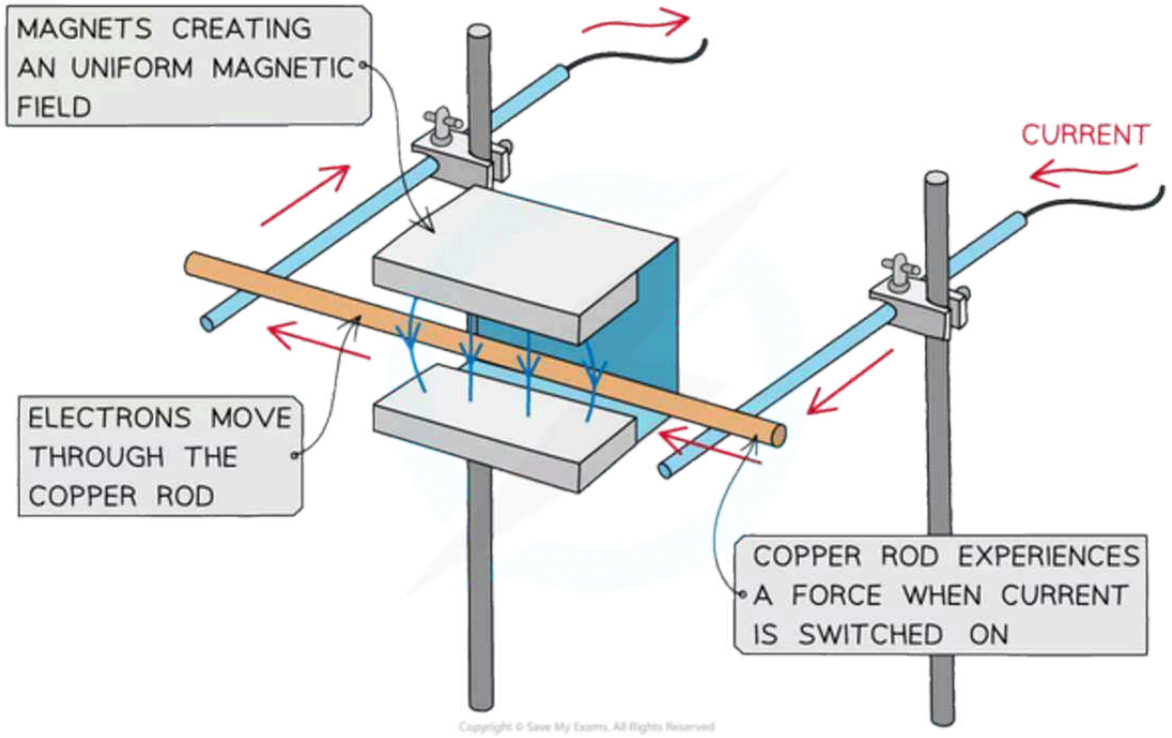
Force on a Current-Carrying Conductor

Your notes

Force on a Current-Carrying Conductor

- A current-carrying conductor produces its own magnetic field
 - When interacting with an external magnetic field, it therefore will experience a **force**
- A current-carrying conductor will only experience a force if the current through it is **perpendicular** to the direction of the magnetic field lines
 - A simple situation would be a copper rod placed within a uniform magnetic field
 - When current is passed through the copper rod, it experiences a force which makes it move

Force on a Current-Carrying Copper Rod in a Magnetic Field



A copper rod moves within a magnetic field when current is passed through it

- Two ways to reverse the direction of the force (and therefore, the copper rod) are by reversing:
 - The direction of the **current**
 - The direction of the **magnetic field**

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Exam Tip

This phenomenon is sometimes referred to as 'the motor effect'. The direction of the force is determined by Fleming's left-hand rule.


Your notes

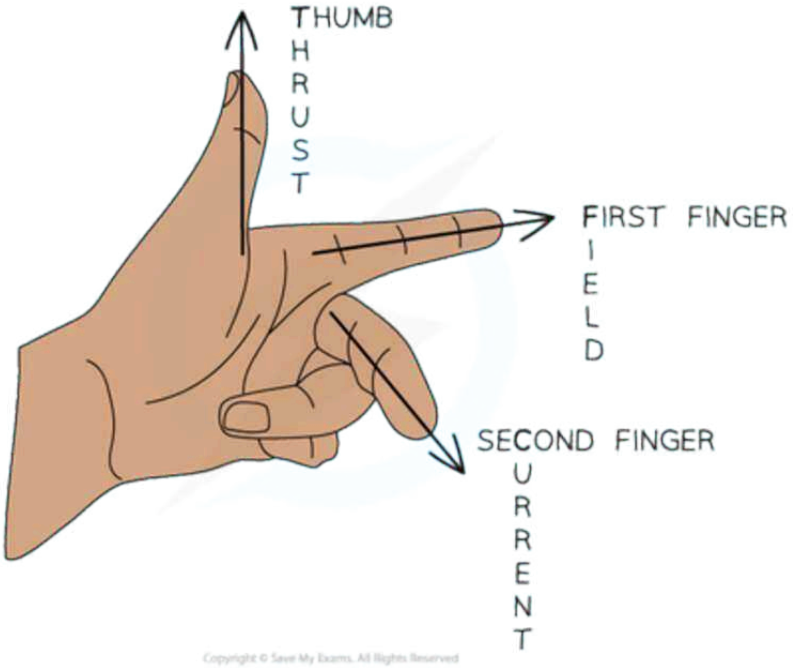
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Left Hand Rule

Your notes

- The **direction** of the **force** (aka the **thrust**) on a current carrying wire depends on the direction of the current and the direction of the magnetic field
- All three will be **perpendicular** to each other
 - This means that sometimes the force could appear to be acting either into or out of the page
- The direction of the force (or thrust) can be worked out by using **Fleming's left-hand rule**:

Fleming's Left-Hand Rule

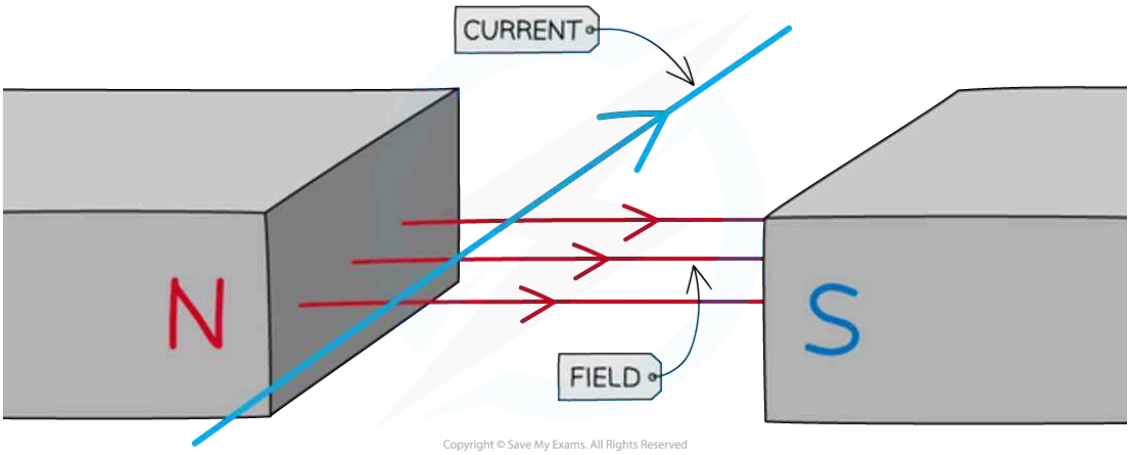


Fleming's left-hand rule can be used to determine directions of the force (thumb), magnetic field (first finger) and current (second finger)

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Worked example

Use Fleming's left-hand rule to show that if the current-carrying wire is placed into the magnetic field between the poles of the magnet, as shown below, there will be a downwards force acting on the wire.



Answer:

Step 1: Determine the direction of the magnetic field

- Start by pointing your **F**irst **F**inger in the direction of the (magnetic) **F**ield.

Step 2: Determine the direction of the current

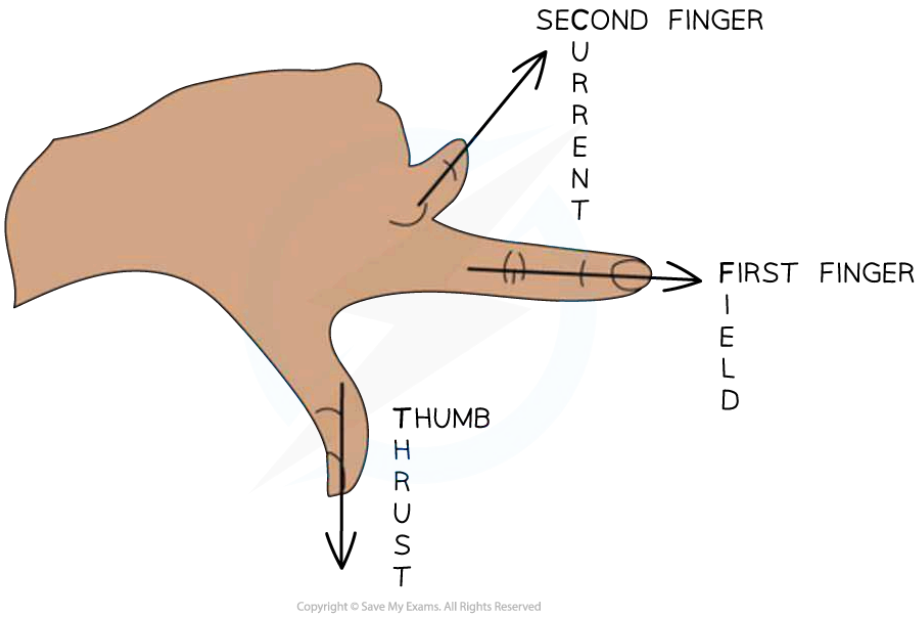
- Now rotate your hand around the first finger so that the se**C**ond finger points in the direction of the **C**urrent

Step 3: Determine the direction of the force

- The **TH**umb will now be pointing in the direction of the **TH**rust (the force)
- Therefore, this will be the direction in which the wire will move

Your notes

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Exam Tip

Remember that the magnetic field is always in the direction from **North** to **South** and current is always in the direction of a **positive** terminal to a **negative** terminal.

Feel free to use Fleming's left hand rule in your exam, just don't make it too distracting for other students!

Your notes

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Fields Around Parallel Conductors

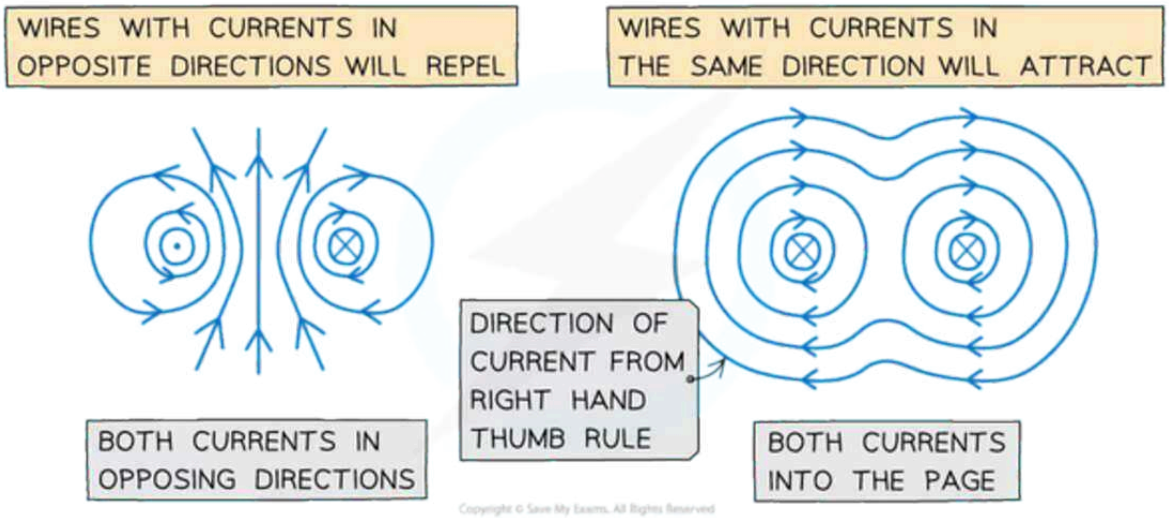
Your notes

Fields Around Parallel Wires

- A current carrying conductor, such as a wire, produces a magnetic field around it
- The direction of the field depends on the direction of the current through the wire
 - This is determined by the **right hand thumb rule**

- Parallel current-carrying conductors will therefore either attract or repel each other
 - If the currents are in the **same** direction in both conductors, the magnetic field lines between the conductors cancel out – the conductors will **attract** each other
 - If the currents are in the **opposite** direction in both conductors, the magnetic field lines between the conductors push each other apart – the conductors will **repel** each other

Repulsion & Attraction of Current-Carrying Wires



Both wires will attract if their currents are in the same direction and repel if in opposite directions

- When the conductors **attract**, the direction of the magnetic forces will be **towards** each other
- When the conductors **repel**, the direction of the magnetic forces will be **away** from each other
- The magnitude of each force depends on the amount of current and the length of the wire

Force per Unit Length Between Two Parallel Conductors

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Your notes

- $\frac{F}{L}$ is the force per unit length between two parallel currents I_1 and I_2 separated by a distance r
- The force is **attractive** if the currents are in the **same direction** and **repulsive** if they are in **opposite directions**
- It is calculated using the equation:

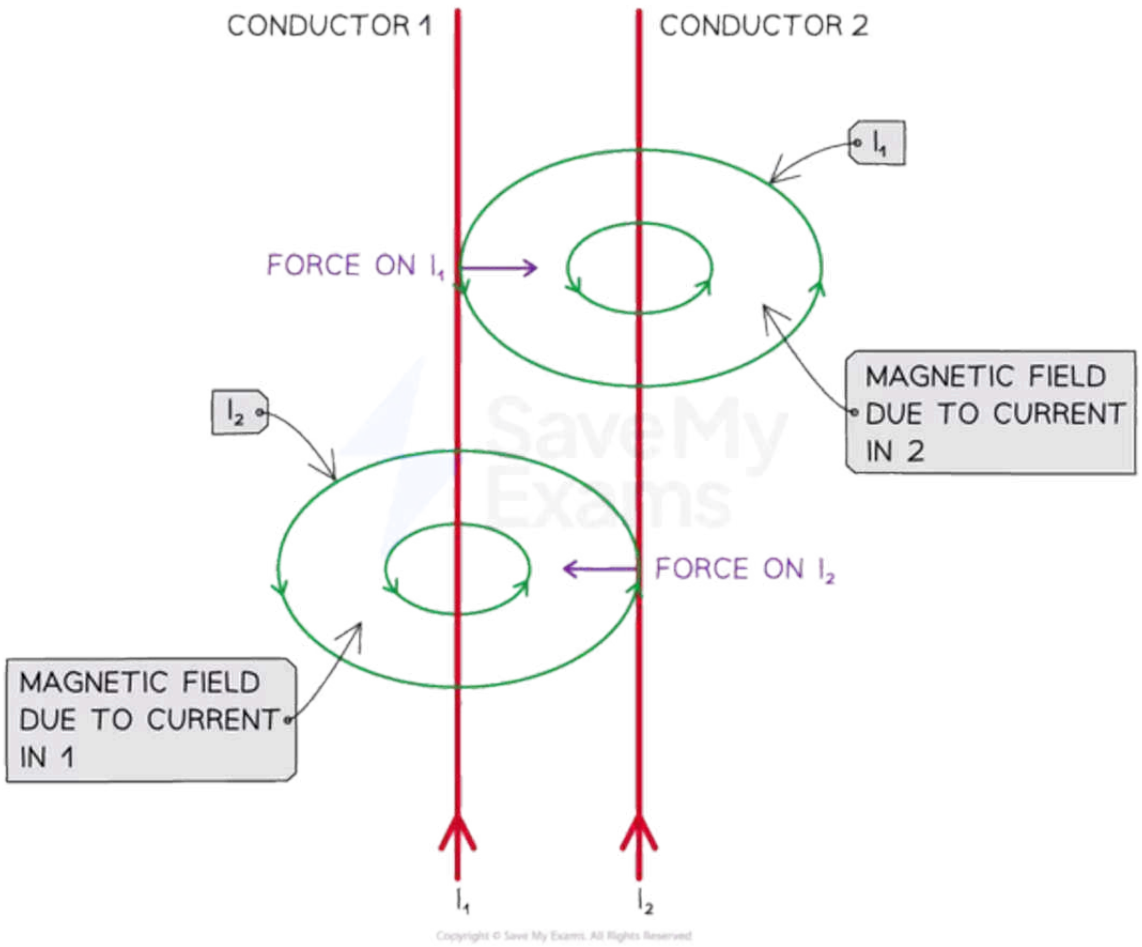
$$\frac{F}{L} = \mu_0 \frac{I_1 I_2}{2\pi r}$$

- Where:
 - F is the force applied between the two parallel wires (N)
 - L is the length of each parallel conductor (m)
 - μ_0 is the constant for the magnetic permeability of free space = $4\pi \times 10^{-7}$ N A^{-2}
 - I_1 is the current through the first conducting wire (A)
 - I_2 is the current through the second conducting wire (A)
 - r is the separation between the two conducting wires (m)

Forces on Current-Carrying Wires

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Your notes



The forces on each of the current-carrying wires are equal and opposite in direction

Obtaining the Equation

- The force from wire 2 on wire 1, $F_2 = B_2 I_1 L \sin(\theta)$
- In this situation the magnetic field is perpendicular to the current in the wire, so $\sin(\theta) = 1$
- $F_2 = -F_1$ so the force between them is F
- The force on a unit length of the wires is then given by $\frac{F}{L} = \frac{B_2 I_1 L}{L}$

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- Hence, $\frac{F}{L} = B_2 I_1$

Your notes

- The magnitude of the magnetic field at a radial distance, *r* away from the current conducting wire is:

$$B = \frac{\mu_0 I}{2\pi r}$$

 - In this case the magnetic field strength from B_2 at a distance *r* away from wire 2 is: $B_2 = \frac{\mu_0 I_2}{2\pi r}$

- Substituting for B_2 into the force per unit length equation gives us: $\frac{F}{L} = \left(\frac{\mu_0 I_2}{2\pi r}\right) I_1$

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Worked example

Two long, straight, current-carrying conductors, WX and YZ, are held at a close distance, as shown in diagram 1.

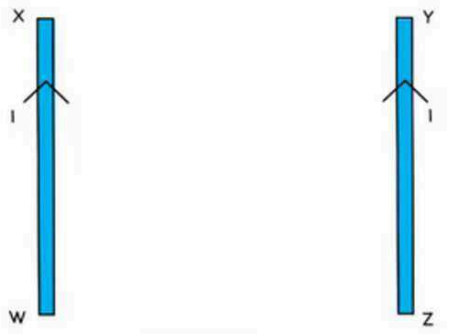


diagram 1

The conductors each carry the same magnitude current in the same direction. A plan view from above the conductors is shown in diagram 2.



diagram 2

On diagram 2, draw arrows, one in each case, to show the direction of:

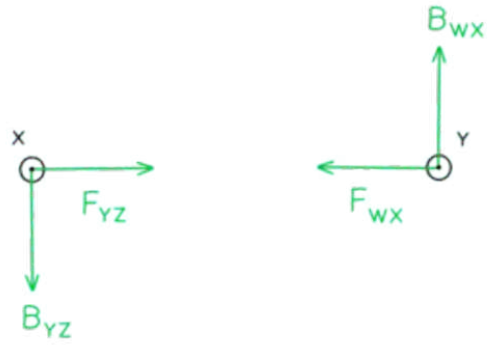
- The magnetic field at X due to the current in wire YZ (label this arrow B_{YZ})
- The force at X as a result of the magnetic field due to the current in the wire YZ (label this arrow F_{YZ})
- The magnetic field at Y due to the current in wire WX (label this arrow B_{WX})
- The force at Y as a result of the magnetic field due to the current in the wire WX (label this arrow F_{WX})

Answer:

Your notes

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Your notes



- Newton's Third Law states:
 - When two bodies interact, the force on one body is **equal but opposite** in direction to the force on the other body
- Therefore, the forces on the wires act in equal but opposite directions

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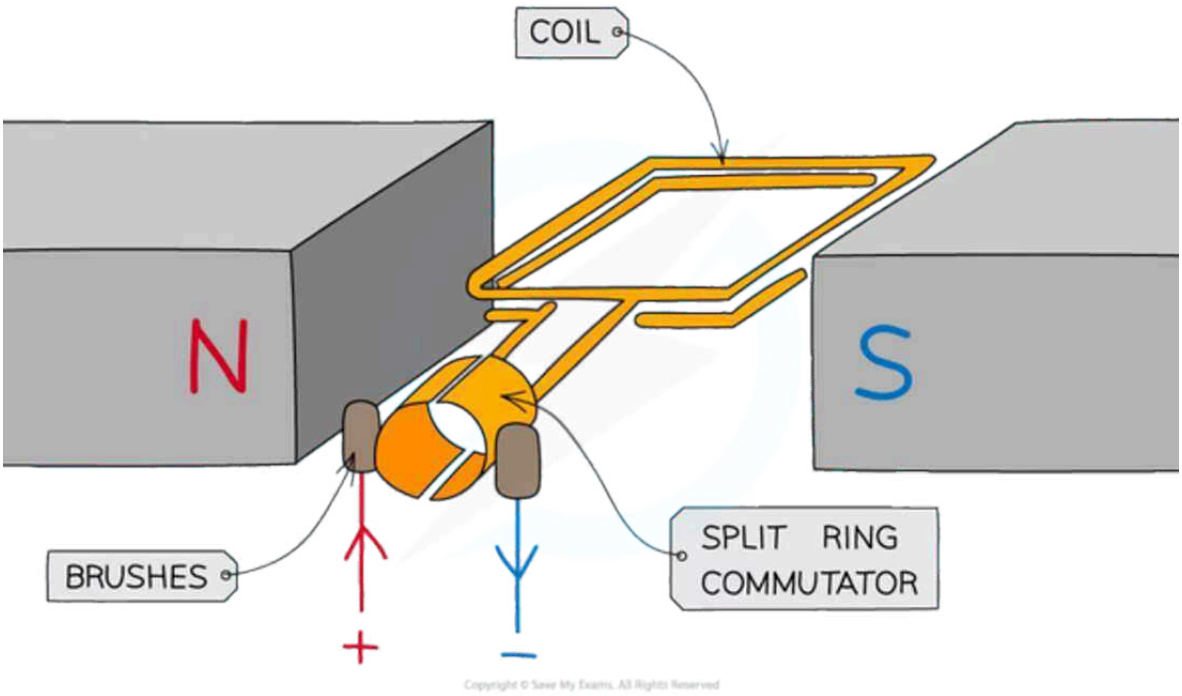
Electric Motors

Your notes

The DC Motor

- The **motor effect** can be used to create a simple **d.c** electric motor
- The simple d.c. motor consists of a coil of wire (which is free to rotate) positioned in a **uniform magnetic field**:

Structure of a Simple D.C. Motor



A simple D.C. electric motor consists of a coil that rotates in a magnetic field, a split ring commutator and brushes

- This causes the coil to **rotate** since it experiences a **turning effect**
- The turning effect is increased by increasing:
 - The number of turns on the coil
 - The current
 - The strength of the magnetic field

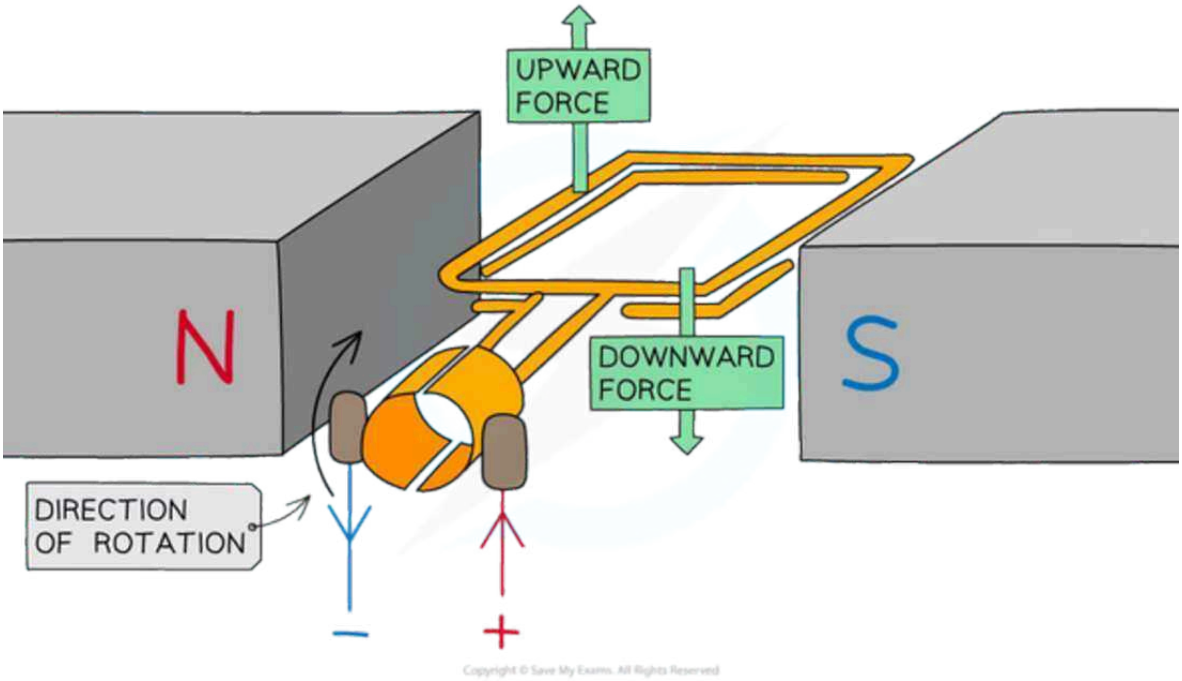
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Operation of a DC Motor

Your notes

- When the current is flowing in the coil at 90° to the direction of the magnetic field:
 - The **current** creates a **magnetic field** around the coil
 - The magnetic field produced around the coil interacts with the field produced by the magnets
 - This results in a **force** being exerted on the coil
 - The direction of the force can be determined using **Fleming's left-hand rule**
 - As current will flow in **opposite** directions on each side of the coil, the force produced from the magnetic field will push one side of the coil **up** and the other side of the coil **down**
- This will cause the coil to **rotate**, and it will continue to rotate until it is in the vertical position
 - In the vertical position **momentum** keeps the coil turning until the magnetic force takes over again
- The **split ring commutator** swaps the contacts of the coil
 - This reverses the direction in which the current is flowing every half turn
 - This keeps the current leaving the motor in the **same direction** (d.c)
- Reversing the direction of the current will also reverse the direction in which the forces are acting
 - As a result, the coil will continue to **rotate**

Force on Coil in a D.C. Motor



Forces on coil after commutator has reversed the direction of the current

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Your notes

- The split-ring commutator reverses the direction of the current in the coil every **half turn**
 - This will keep the coil rotating continuously as long as the current is flowing

Factors Affecting the D.C Motor

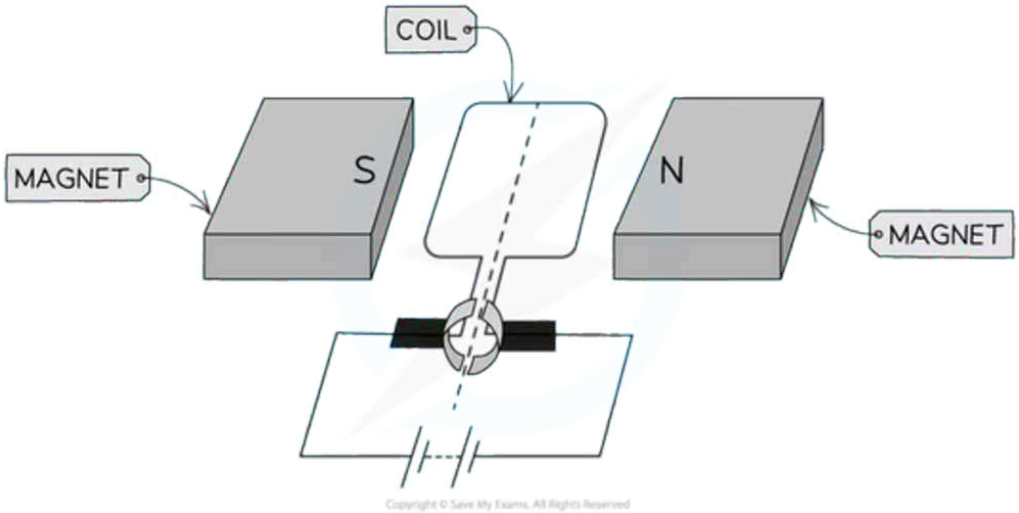
- The **speed** at which the coil rotates can be increased by:
 - Increasing the **current**
 - Use a **stronger magnet**
- The **direction of rotation** of coil in the d.c motor can be changed by:
 - Reversing the direction of the **current**
 - Reversing the direction of the magnetic field by reversing the **poles** of the magnet
- The **force** supplied by the motor can be increased by:
 - Increasing the **current** in the coil
 - Increasing the strength of the **magnetic field**
 - Adding **more turns** to the coil

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Your notes

Worked example

A d.c motor is set up as shown below.

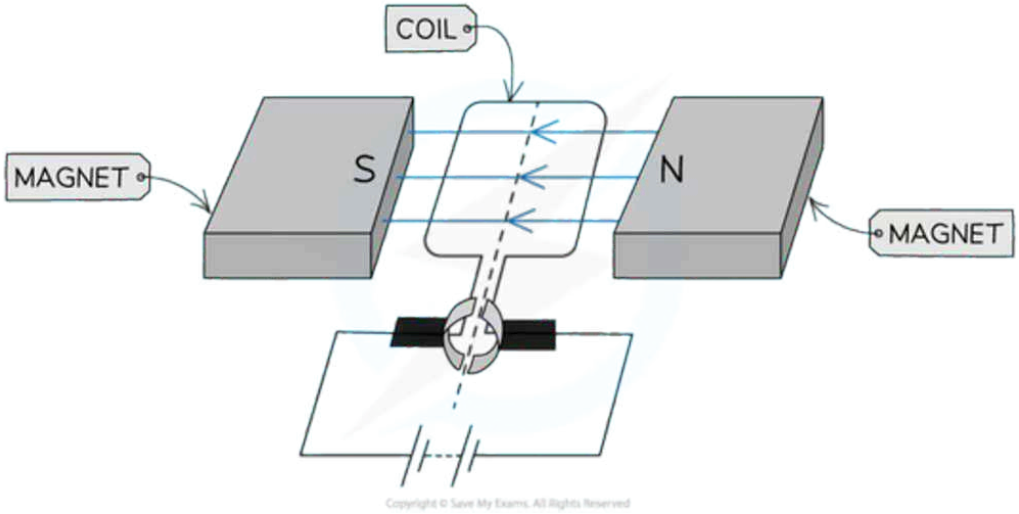


Determine whether the coil will be rotating clockwise or anticlockwise.

Answer:

Step 1: Draw arrows to show the direction of the magnetic field lines

- These will go from the north pole of the magnet to the south pole of the magnet

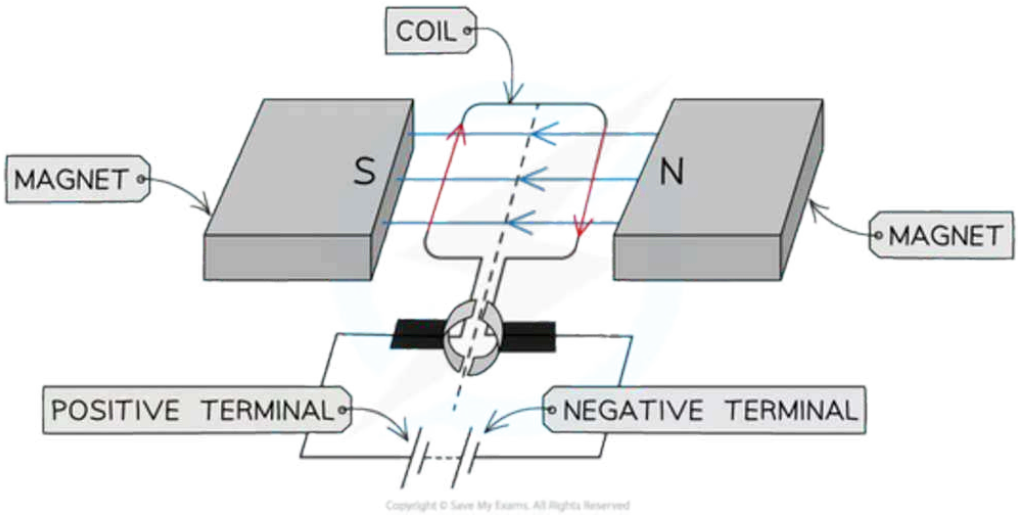


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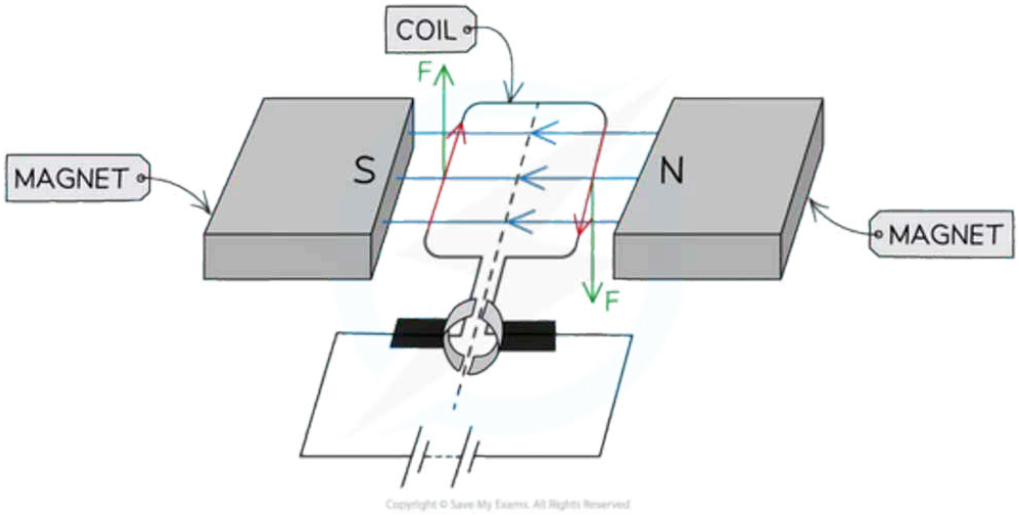
Step 2: Draw arrows to show the direction the current is flowing in the coils

- Current will flow from the positive terminal of the battery to the negative terminal



Step 3: Use Fleming's left-hand rule to determine the direction of the force on each side of the coil

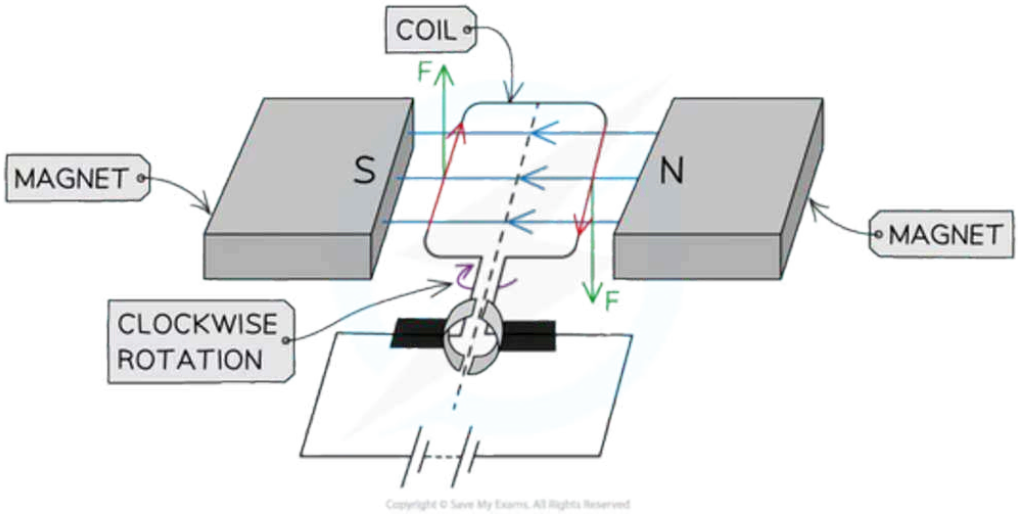
- Start by pointing your **F**irst **F**inger in the direction of the (magnetic) **F**ield
- Now rotate your hand around the first finger so that the se**C**ond finger points in the direction of the **C**urrent
- The **TH**umb will now be pointing in the direction of the **TH**rust (the force)



Step 4: Use the force arrows to determine the direction of rotation

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- The coil will be turning **clockwise**



Your notes

Exam Tip

It is important to remember all the steps that causes the rotation of the coil in a d.c. motor.

Use Fleming's left-hand rule to convince yourself of the direction of the forces on each side of the coil. These should be in opposite directions because the direction of the current through them is in opposite directions.

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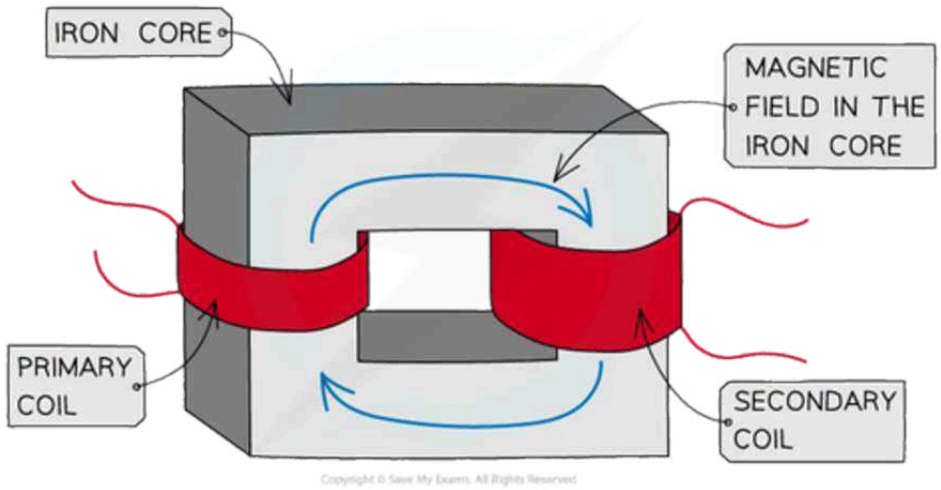
Transformers

Your notes

Transformer

- A **transformer** is an electrical device that can be used to increase or decrease the **potential difference** of an **alternating current** (voltage transformations)
 - This is achieved using the **generator effect**
- A basic transformer consists of:
 - A **primary coil**
 - A **secondary coil**
 - A **soft iron core**
- Iron is used because it is easily **magnetised**

Structure of a Transformer



Structure of a transformer consists of a soft iron core, and a primary and secondary coil

- An **alternating current** is supplied to the **primary coil**
- The **current** is continually **changing direction**
 - This means it will produce a **changing magnetic field** around the primary coil
- The iron core is **easily magnetised**, so the changing magnetic field passes through it
- As a result, there is now a **changing magnetic field** inside the **secondary coil**
 - This changing field **cuts** through the secondary coil and **induces a potential difference**
- As the magnetic field is continually changing the potential difference induced will be **alternating**

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- The alternating potential difference will have the **same frequency** as the alternating current supplied to the primary coil
- If the secondary coil is part of a **complete circuit** it will cause an **alternating current** to flow


Your notes

Step-up & Step-down Transformers

- A transformer consists of a primary and secondary coil
 - The **primary** coil is the **first** coil
 - The **second** coil is the **second** coil
- A step-up transformer **increases** the **potential difference** of a power source
 - A step-up transformer has **more turns** on the **secondary coil** than on the primary coil ($N_s > N_p$)
- A **step-down** transformer **decreases** the **potential difference** of a power source
 - A step-down transformer has **fewer turns** on the **secondary coil** than on the primary coil ($N_s < N_p$)

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Transformer Calculations


Your notes

Transformer Calculations

- The **output potential difference** (voltage) of a transformer depends on:
 - The **number of turns** on the primary and secondary coils
 - The **input potential difference** (voltage)
- It can be calculated using the equation:

$$\frac{\text{P.D. across primary coil}}{\text{P.D. across secondary coil}} = \frac{\text{number of turns on primary coil}}{\text{number of turns on secondary coil}}$$

- This equation can be written using symbols as follows:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

- Where
 - V_p = potential difference (voltage) across the primary coil in volts (V)
 - V_s = potential difference (voltage) across the secondary coil in volts (V)
 - n_p = number of turns on primary coil
 - n_s = number of turns on secondary coil
- The equation above can be flipped upside down to give:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

- The equations above show that:
 - The **ratio** of the potential differences across the primary and secondary coils of a transformer is **equal** to the ratio of the number of turns on each coil

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Your notes

Worked example

A transformer has 20 turns on the primary coil and 800 turns on the secondary coil. The input potential difference across the primary coil is 500 V.

a) Calculate the output potential difference

b) State what type of transformer this is

Answer

Part (a)

Step 1: List the known quantities

- Number of turns in primary coil, $N_P = 20$
- Number of turns in secondary coil, $N_S = 800$
- Voltage in primary coil, $V_P = 500$ V

Step 2: Write the equation linking the output potential difference (V_S) to the known quantities

- There will be less rearranging to do if V_S is on the top of the fraction

$$\frac{N_S}{N_P} = \frac{V_S}{V_P}$$

Step 3: Rearrange the equation to make V_S the subject

$$V_S = \frac{N_S V_P}{N_P}$$

Step 4: Substitute the known values into the equation

$$V_S = \frac{800 \times 500}{20} = 20\,000 \text{ V}$$

Part (b)

The secondary voltage is larger than the primary, therefore this is a step-up transformer

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Exam Tip

When you are using the transformer equation make sure you have used the **same letter** (p or s) in the **numerators** (top line) of the fraction and the **same letter** (p or s) in the **denominators** (bottom line) of the fraction.

There will be less rearranging to do in a calculation if the variable which you are trying to find is on the numerator (top line) of the fraction.

The individual loops of wire going around each side of the transformer should be referred to as **turns** and **not** coils.



Your notes

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High-Voltage Transmission

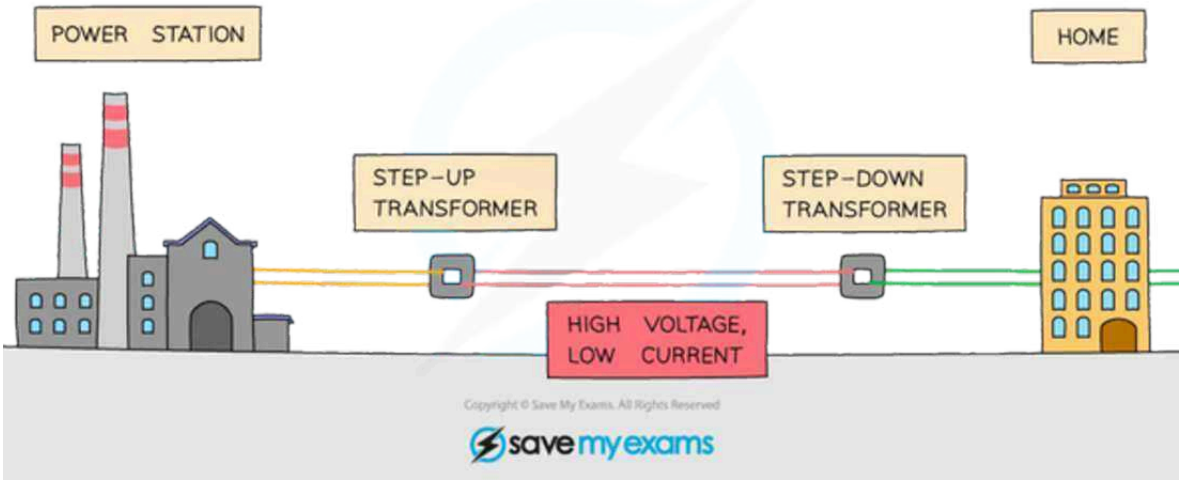
Your notes

- Transformers have a number of roles:
 - They are used to increase the potential difference of electricity before it is transmitted across the national grid
 - They are used to lower the high voltage electricity used in power lines to the lower voltages used in houses
 - They are used in adapters to lower mains voltage to the lower voltages used by many electronic devices

Advantages of High Voltage Transmission

- When electricity is transmitted over large distances, the **current** in the wires **heats** them, resulting in **energy loss**
- To transmit the same amount of **power** as the input power the **potential difference** at which the electricity is transmitted should be **increased**
 - This will result in a **smaller current being transmitted** through the power lines
 - This is because $P = IV$, so if V increases, I must decrease to transmit the same power
- A **smaller current** flowing through the power lines results in **less heat** being produced in the wire
 - This will **reduce the energy loss** in the power lines

Model of High-Voltage Transmission



Electricity is transmitted at high voltage, reducing the current and hence power loss in the cables

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Cambridge O Level Physics

Your notes

4.6 Uses of an Oscilloscope

Contents

Uses of an Oscilloscope

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Uses of an Oscilloscope

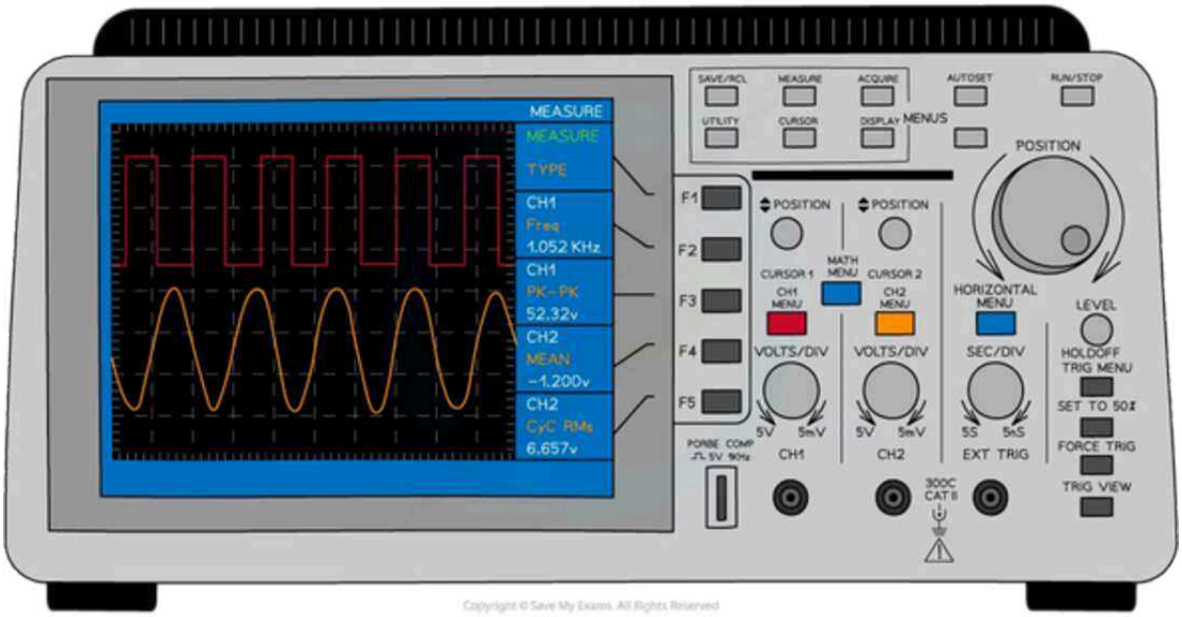
Your notes

Uses of an Oscilloscope

Displaying Waveforms

- An **oscilloscope** is a device that can be used to study a rapidly **changing signal**, such as:
 - A **sound wave**
 - An **alternating current**

An Oscilloscope



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Oscilloscopes have lots of dials and buttons, but their main purpose is to display and measure changing signals like sound waves and alternating current

- When a microphone is connected to an oscilloscope, the (longitudinal) sound wave is displayed as though it were a transverse wave on the screen
- An alternating current (A.C.) on an oscilloscope is also represented as a transverse wave.
- Using the oscilloscope the frequency and amplitude of these waves can be determined
- The x-axis is the **time** and the y-axis is the **voltage (**or **y-gain)**

Measuring P.D. and Time Intervals

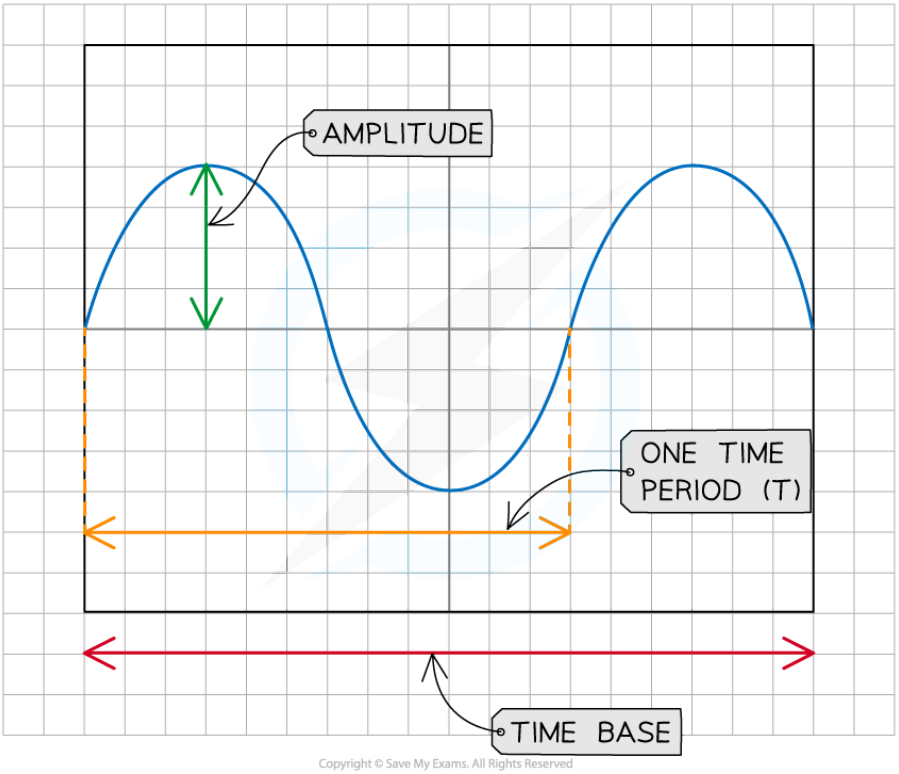
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Your notes

- The p.d. can be measured using the oscilloscope's vertical axis called the **y-gain**
 - This is done by measuring the wave amplitude, by counting the number of squares from the centre of the wave to the peak or trough of the waveform, and applying the correct scale
 - The vertical axis has the units volts per division, **volts/div**
 - It is possible to adjust the y-gain scale by turning the correct switch on the oscilloscope
 - The y-gain may have a scale of 1 volt per division but by zooming in it is possible to increase the scale to 10 volts per division for example

- Short intervals of time can be measured using the oscilloscope's x-axis called the **time-base**:
 - The time base is **how many seconds each division represents** measured commonly in seconds per division, **s/div**, or seconder per centimetre, **s/cm**
 - Measuring time is done by measuring the time-period of one wavelength, by counting the number of squares from one point on one wave to the equivalent point on the next wave
 - It is possible to adjust the time-base scale by turning the correct switch on the oscilloscope
 - The time-base may have a scale of 1 second per division but it is possible to increase or decrease the scale by zooming in or out

Wavelength and Amplitude



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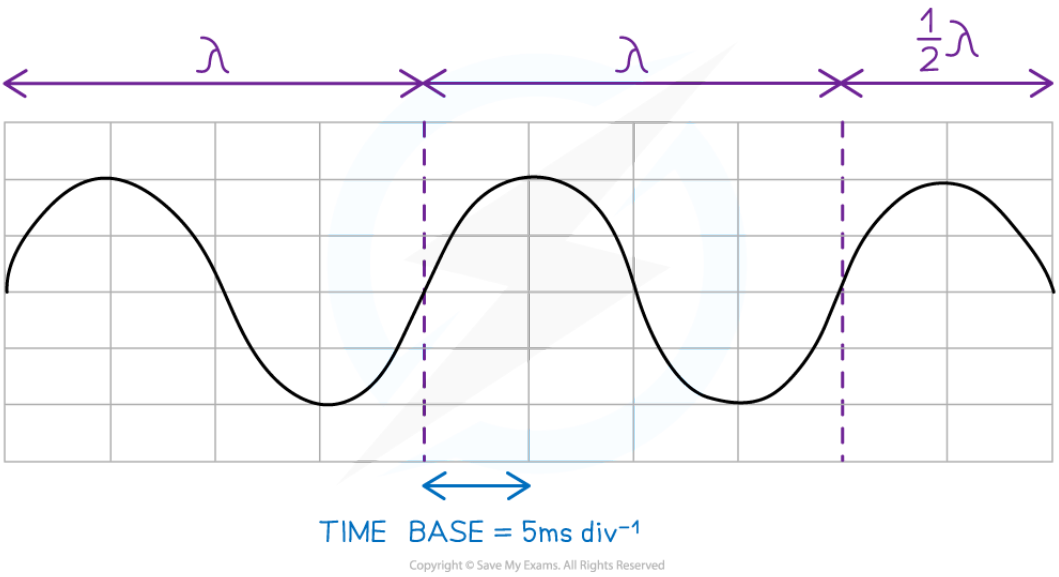
A sound wave is displayed as though it were a transverse wave on the screen of the oscilloscope. The amplitude can be used to measure the y-gain of the waveform. The time base can be used to measure a full time-period of the wave cycle

Your notes

Calculating Frequency

- Use as many wavelengths shown on the screen as possible to reduce uncertainties
- Dividing the total time by the number of wavelengths will give the time-period *T* (time taken for one complete oscillation)
- The **frequency** is then determined using the equation $f = \frac{1}{T}$

An Example of Counting Wavelengths



An Oscilloscope display showing $2\frac{1}{2}$ wavelengths and a time-base setting of 5 ms/div

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Cambridge O Level Physics

Your notes

5.1 The Nuclear Model of the Atom

Contents

- The Atom
- The Nucleus

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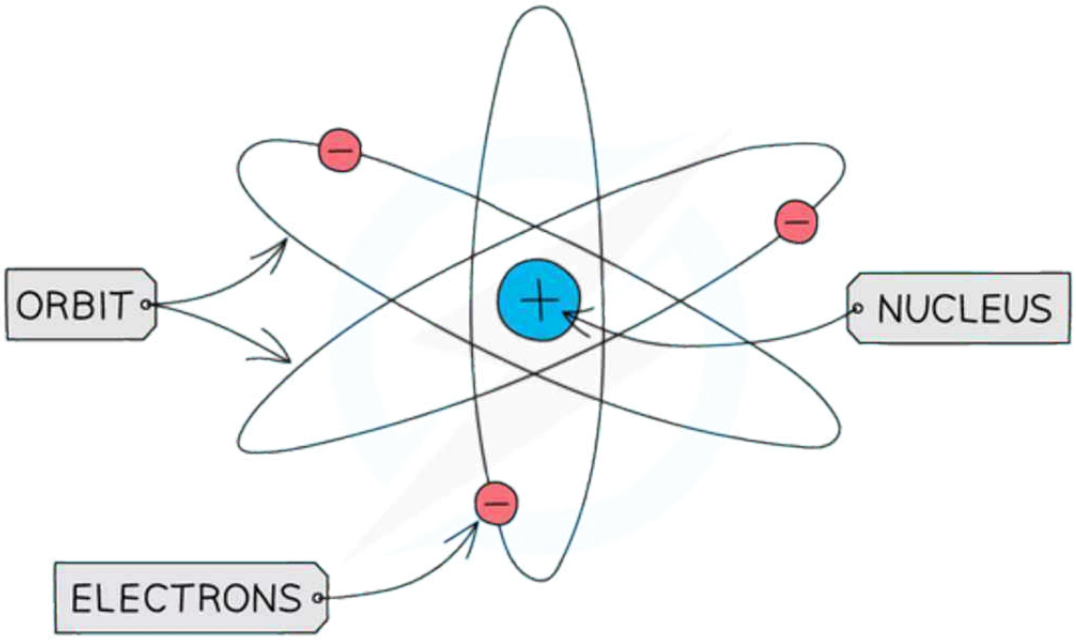
The Atom

Your notes

Atomic Structure

- Atoms are the building blocks of **all matter**
 - They are incredibly small
- Atoms have a tiny **nucleus** at their centre, with **electrons** orbiting around the nucleus
- They consist of small **positively** charged nuclei, surrounded by **negatively** charged electrons

The Structure of an Atom



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An atom has a small positive nucleus, surrounded by orbiting negative electrons

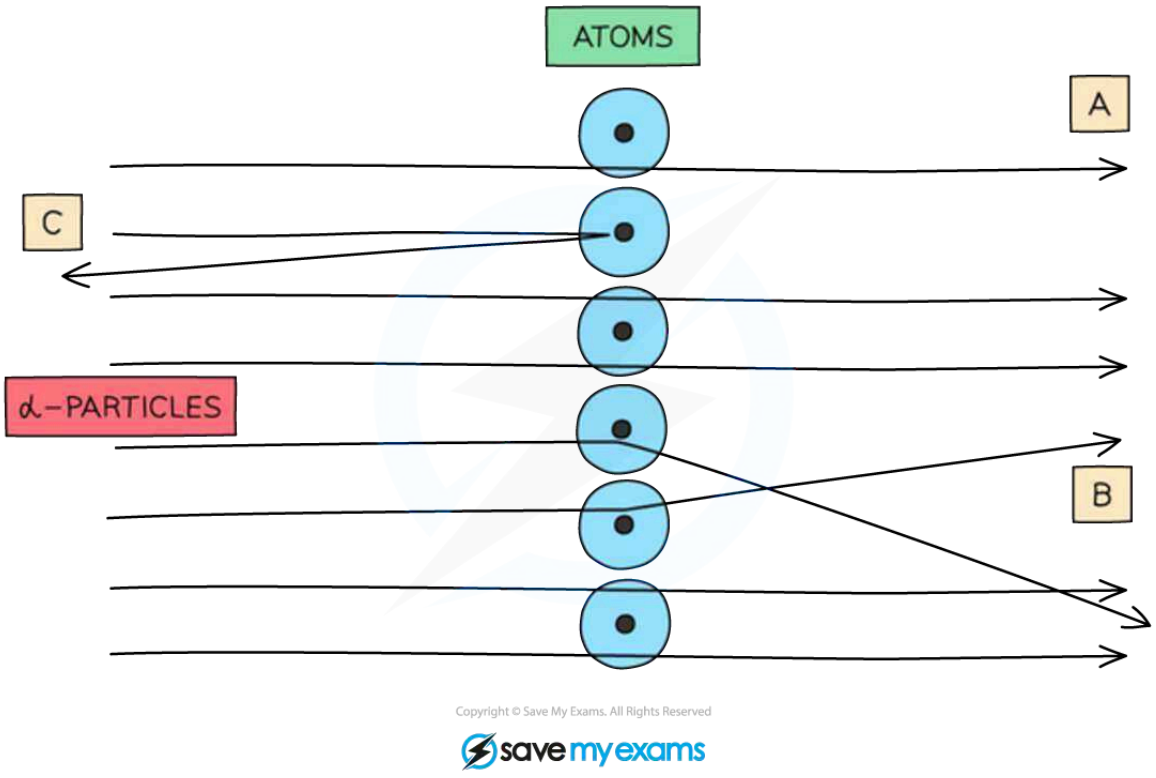
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Rutherford's Experiment

Your notes

- In 1909 **Ernest Rutherford** was investigating their ideas about the structure of the atom
- This involved the scattering of alpha (α) particles by a sheet of thin metal supports the nuclear model of the atom
- A beam of **alpha particles** was directed at a thin gold foil
- They expected the alpha particles to travel straight through the gold foil with only a small amount of deflection
- Instead, they discovered that :
 - Most of the alpha particles **passed straight through** the foil
 - Some of the alpha particles **changed direction** but continued through the foil
 - A few of the alpha particles **bounced back** off the gold foil

Alpha Particles Passing Through Atoms in a Gold Foil



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When α-particles are fired at thin gold foil most of them pass straight through but a very small number bounce straight back

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- When α-particles are fired at thin pieces of gold foil:
 - **The majority of them go straight through (A)**
 This happens because the atom is mainly **empty space**
 - **Some are deflected through small angles (B)**
 This happens because the positive α-particles are repelled by the **positive nucleus** which contains **most of its mass**
 - **A very small number are deflected straight back (C)**
 This is because the nucleus is **extremely small**


Your notes

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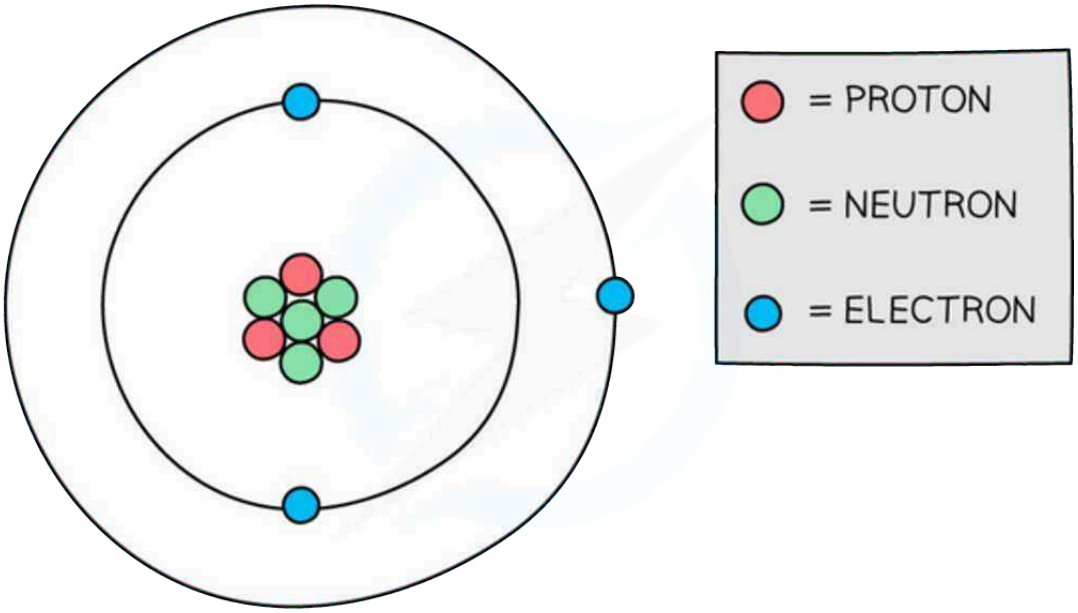
The Nucleus

Your notes

Composition of the Nucleus

- A nucleus is made up of **positively charged protons** and **neutrally charged neutrons**

The Protons, Neutrons and Electrons in an Atom



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Protons and neutrons are found in the nucleus of an atom

- Protons have a positive charge, whilst neutrons have no charge
 - This is why the nucleus is positive overall

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Exam Tip

Be careful with your terminology:

- Atom = nucleus (proton and neutron) **and** electrons
- Nucleus = protons and neutrons at the centre of the atom

Your notes

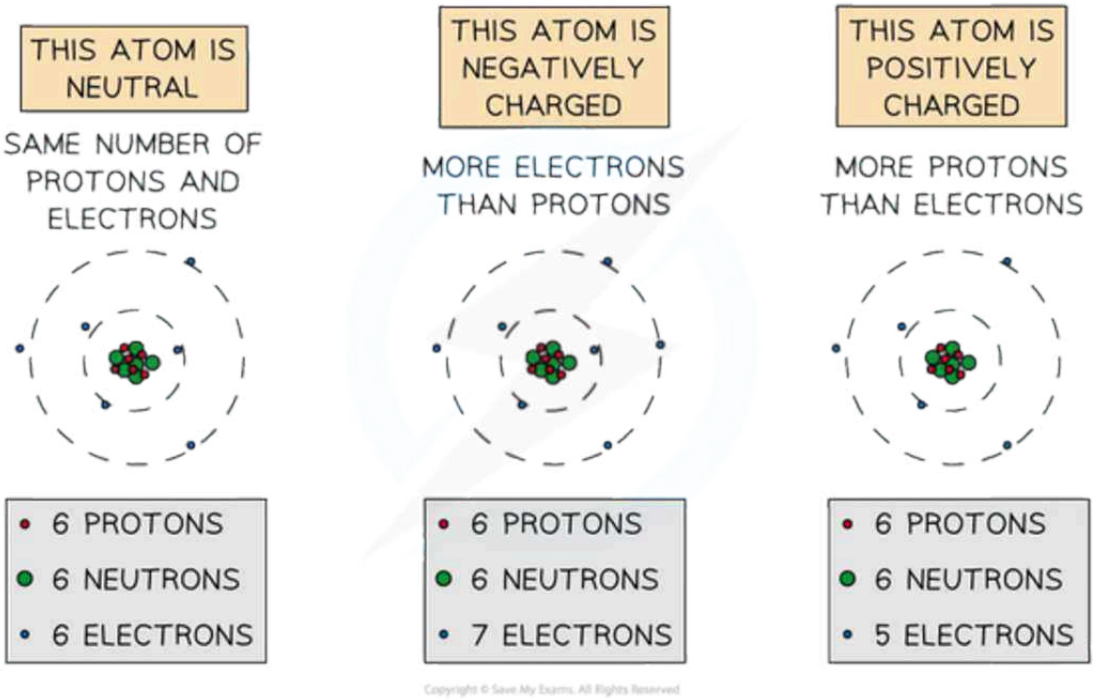
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Atoms & Ions

Your notes

- An ion is an **electrically charged** atom or group of atoms formed by the **loss** or **gain** of **electrons**
 - An atom will lose or gain electrons to become **more stable**
- A stable atom is normally **electrically neutral**
 - This means it has the same number of protons (positive charge) and electrons (negative charge)
- **Positive ions** are therefore formed when atoms **lose** electrons
 - There will be more protons than electrons
- **Negative ions** are therefore formed when atoms **gain** electrons
 - There will be more electrons than protons

Neutral, Positively and Negatively Charged Atoms



The difference between positive and negative ions depends on the number of elections

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Exam Tip

You may hear the term 'net charge'. This just means the 'overall' charge of the atom. If an atom has 5 protons, 5 neutrons and 6 electrons, it has a **net** negative charge because it's a negative ion (more electrons than protons).

Remember which way around the charges are by **p**roton being **p**ositive.



Your notes

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Describing the Nucleus


Your notes

Proton Number, Z

- The number of protons in an atom is called its **proton number** (it can also be called the atomic number)
 - Elements in the periodic table are ordered by their atomic number
 - Therefore, the number of protons determines which element an atom is
- The atomic number of a particular element is **always the same**
- For example:
 - Hydrogen has an atomic number of 1. It always has just one proton
 - Sodium has an atomic number of 11. It has 11 protons
 - Uranium has an atomic number of 92. It has 92 protons
- The atomic number is also equal to the number of electrons in an atom
 - This is because atoms have the same number of electrons and protons in order to have no overall charge

Nucleon Number, A

- The total number of particles in the nucleus of an atom is called its **nucleon number** (or **mass** number)
- The mass number is the number of protons **and** neutrons in the atom

Calculating the Number of Neutrons

- The number of neutrons can be found by **subtracting** the **atomic** number from the **mass** number

Number of Neutrons = Nucleon Number – Proton Number

- For example, if a sodium atom has a mass number of 23 and an atomic number of 11, then the number of neutrons would be 23 – 11 = 12

Exam Tip

You may have noticed that the number of electrons is not part of the mass number. This is because electrons have a **tiny** mass compared to neutrons and protons. We say their mass is negligible when compared to the particles in the nucleus.

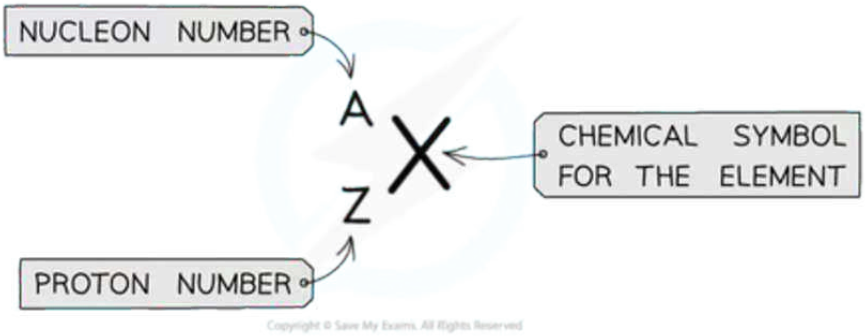
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Nuclide Notation

Your notes

- A **nuclide** is a group of atoms containing the same number of protons and neutrons
 - For example, 5 atoms of oxygen are all the same nuclide but are 5 separate atoms
- Atomic symbols are written in a specific notation called **nuclide** or **ZXA notation**

Nuclide Notation

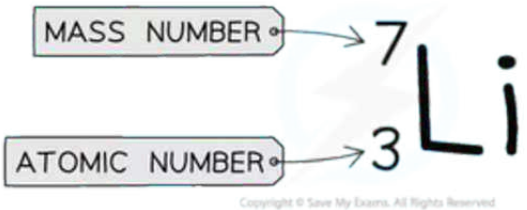


Atomic symbols in AZX Notation describe the constituents of nuclei

- The top number A represents the **nucleon** number or the **mass** number
 - **Nucleon number (A)** = total number of **protons and neutrons** in the nucleus
- The lower number Z represents the **proton** or **atomic** number
 - **Proton number (Z)** = total number of **protons** in the nucleus
- Note: In Chemistry, the nucleon number is referred to as the mass number and the proton number as the atomic number.

The Atomic Symbol of Lithium

- An example of an atomic symbol is:



Atomic symbols, like the one above, describe the constituents of nuclei

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Worked example

The element symbol for gold is Au. How many protons, neutrons and electrons are in the gold atom?



	Protons	Neutrons	Electrons
A	79	79	79
B	197	79	118
C	118	118	79
D	79	118	79

ANSWER: D

Step 1: Determine the atomic and mass number

- The gold atom has an atomic number of 79 (lower number) and a mass number of 197 (top number)

Step 2: Determine the number of protons

- The **atomic** number is equal to the number of **protons**
- The atom has 79 protons

Step 3: Calculate the number of neutrons

- The mass number is equal to the number of protons and neutrons
- The number of neutrons is equal to the mass number minus the atomic number

$$197 - 79 = 118$$

- The atom has 118 neutrons

Step 4: Determine the number of electrons

Your notes

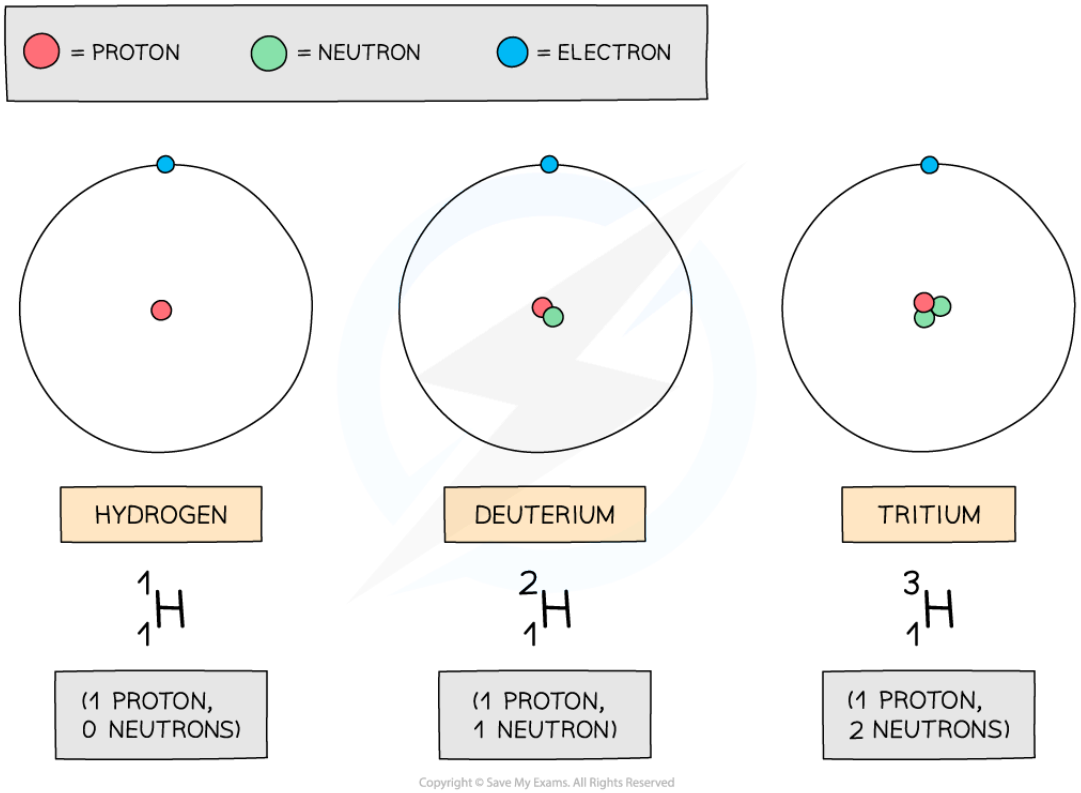
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Isotopes

Your notes

- Although the number of protons in a particular element is always the same, the number of **neutrons** can be different
- **Isotopes** are atoms of the same element that have an equal number of protons but a **different** number of **neutrons**
 - This means that each element can have more than one isotope
- Isotopes tend to be more **unstable** due to their imbalance of protons and neutrons
 - This means they're more likely to decay
- In the diagram below are three isotopes of Hydrogen:

The Three Isotopes of Hydrogen



Hydrogen has three isotopes, each with a different number of neutrons

- Isotopes occur naturally, but some are more rare than others
- For example, about 2 in every 10,000 Hydrogen atoms is Deuterium
 - Tritium is even more rare (about 1 in every billion billion hydrogen atoms)

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Worked example

Which of the following elements are isotopes of each other?

A	$^{35}_{17}\mathrm{Cl}$ and $^{35}_{18}\mathrm{Cl}$
B	$^{238}_{92}\mathrm{U}$ and $^{235}_{92}\mathrm{U}$
C	$^{12}_{6}C$ and $^{14}_{8}\mathrm{C}$
D	$^{16}_{8}\mathrm{O}$ and $^{14}_{7}\mathrm{N}$

Answer: **B**

- In nuclide notion, the top number is the **nucleon** number (number of protons and neutrons) and the bottom number is the **proton** number (number of protons)
- Isotopes are two of the same elements
 - This eliminates option **D** since one is oxygen (O) and the other nitrogen (N)
- Which have the same number of protons
 - This eliminates options **C** and **A**
 - Their proton numbers are different for the same element
- But a different number of neutrons
 - Therefore, the correct answer is **B**



Your notes

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Cambridge O Level Physics

Your notes

5.2 Radioactivity

Contents

- Detection of Radioactivity
- Background Radiation
- The Three Types of Emission
- Radioactive Decay
- Fission & Fusion
- Half-Life
- Uses of Radiation
- Dangers of Radiation

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Detection of Radioactivity

Your notes

Detection of Radioactivity

- Ionising nuclear radiation is measured using a **detector** connected to a **counter**

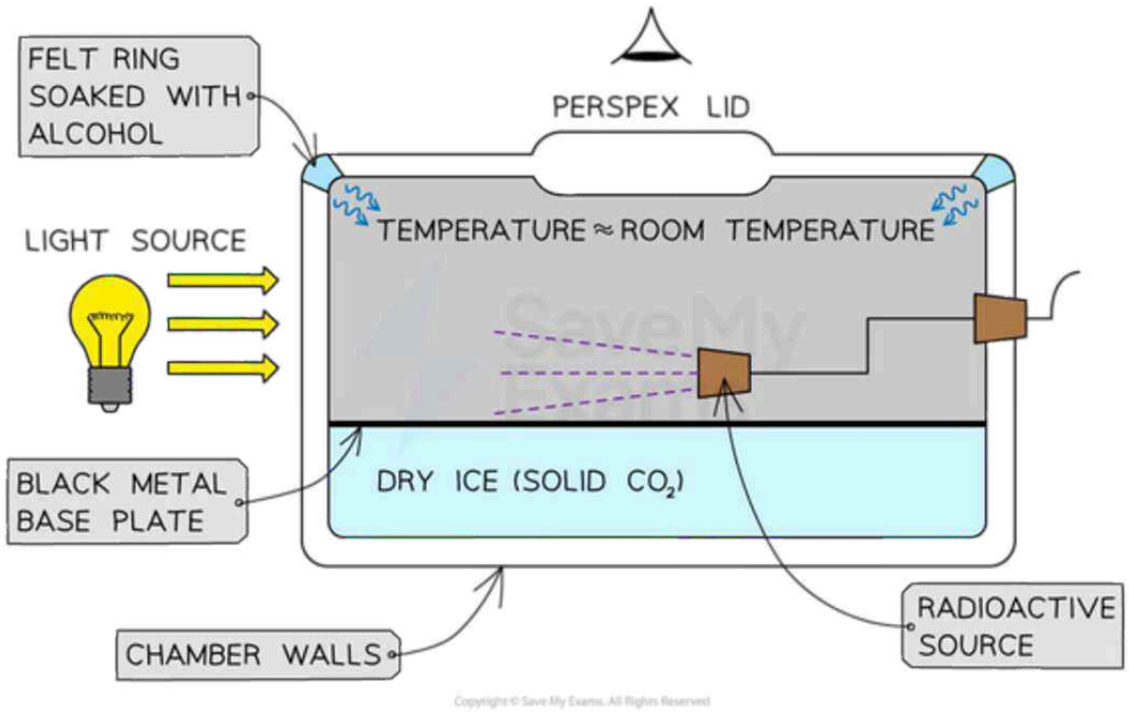
Detection of Alpha Particles

- α-particles are detected using a **cloud chamber** or **spark counter**

Cloud Chambers

- There are several different types of cloud chambers
- A cloud chamber contains:
 - A **metal plate** on the bottom, cooled using **dry ice**
 - A transparent **viewing film** at the top with a **light source** at one side, allowing the observer to identify what is happening
 - A thin film of **alcohol evaporated** inside the chamber forming a vapour
 - A **radioactive source** placed in the chamber
 - A **magnetic field** at right angles to the chamber

A Simple Cloud Chamber Set-Up



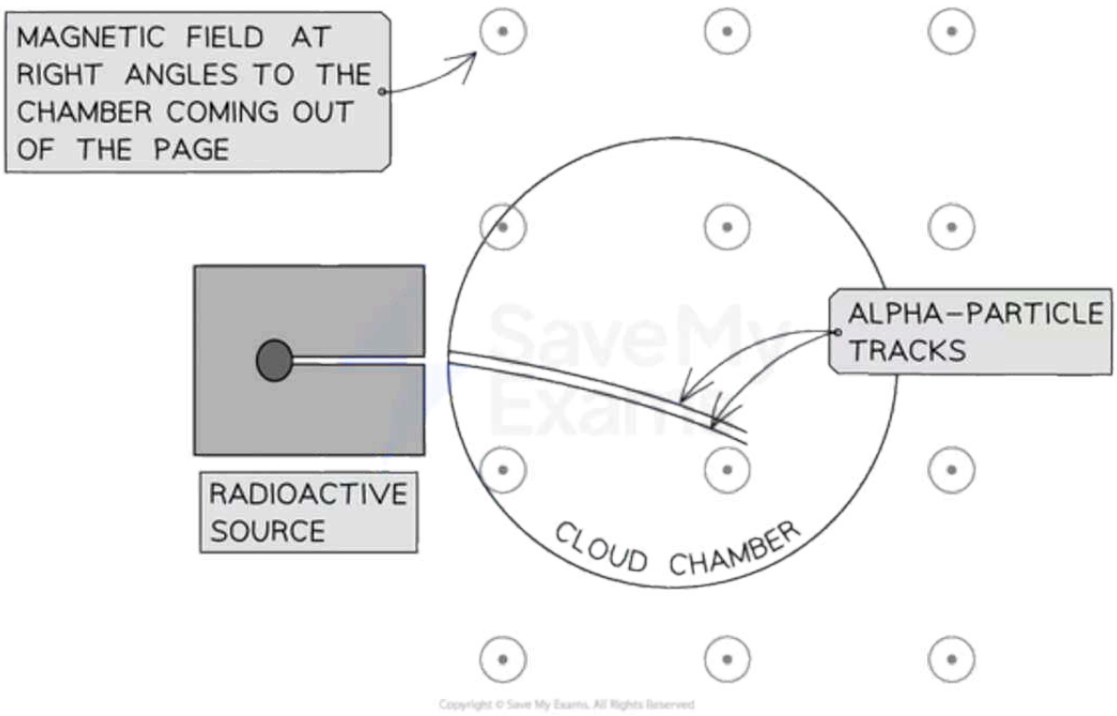
A cloud chamber contains vapour obtained from the cooling of alcohol using dry ice

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- When charged particles pass through the cloud chamber:
 - They **collide** with gas molecules
 - **Creating ions** as the alcohol condenses
 - Forming a **path of condensation** within the chamber
- α-particles can be identified because they produce **thick short tracks** and **curl slowly** in one direction

Your notes

An Alpha Particle Path in a Cloud Chamber



Alpha particles can be identified by their short thick tracks that bend slightly in one direction

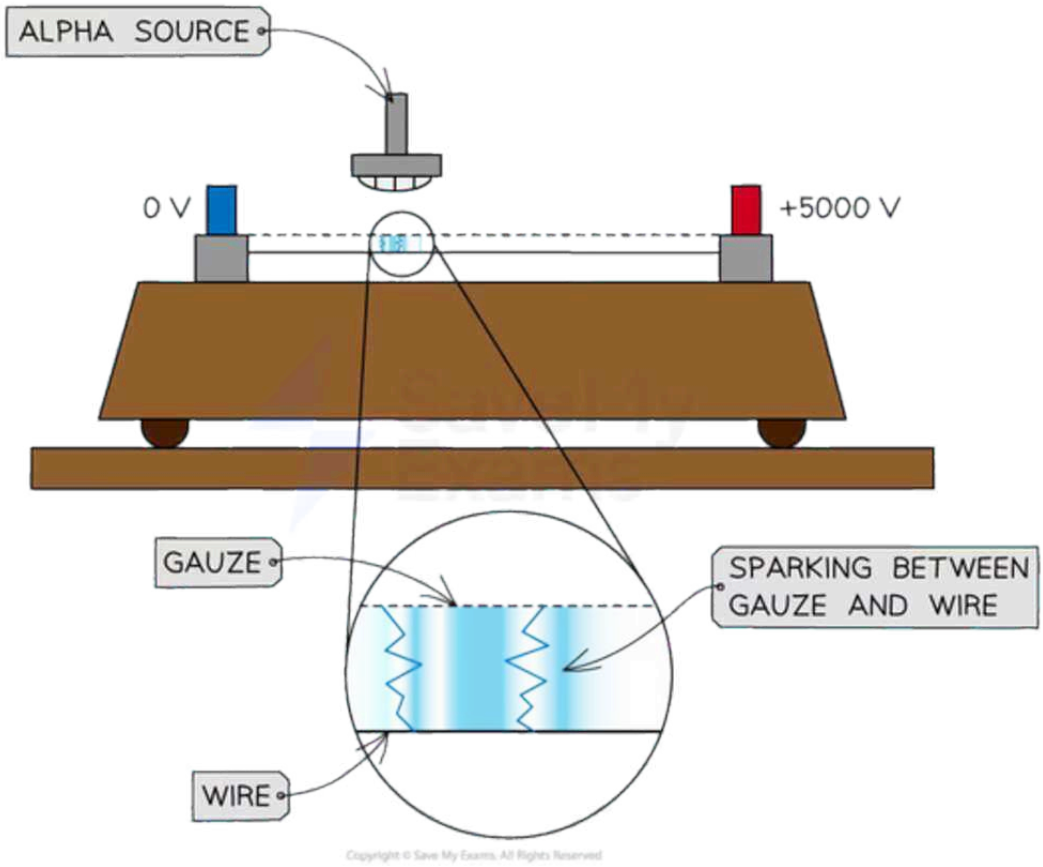
Spark Counters

- A spark counter consists of a **thin metal gauze** mounted very close (about a mmm) to a thin wire
- A large voltage (around 5000 V) is applied across the gauze and the wire to cause sparking between them
- The voltage is then reduced until no more sparking occurs
- When an alpha radiation source is brought close to the gauze it will ionise the air around it
 - Creating sparks between the gauze and the wire

A Spark Counter Set-Up

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Your notes



A spark counter contains a high voltage placed between a gauze and a wire to create sparking

Count Rate

- The **count rate** is the **number** of decays per second recorded by a detector and recorded by the **counter**
 - It is measured in **counts/s** or **counts/min**
- The count rate **decreases** the **further** the detector is **from the source**
 - This is because the radiation becomes more spread out the further away it is from the source

Detection of Beta Particles and Gamma Radiation

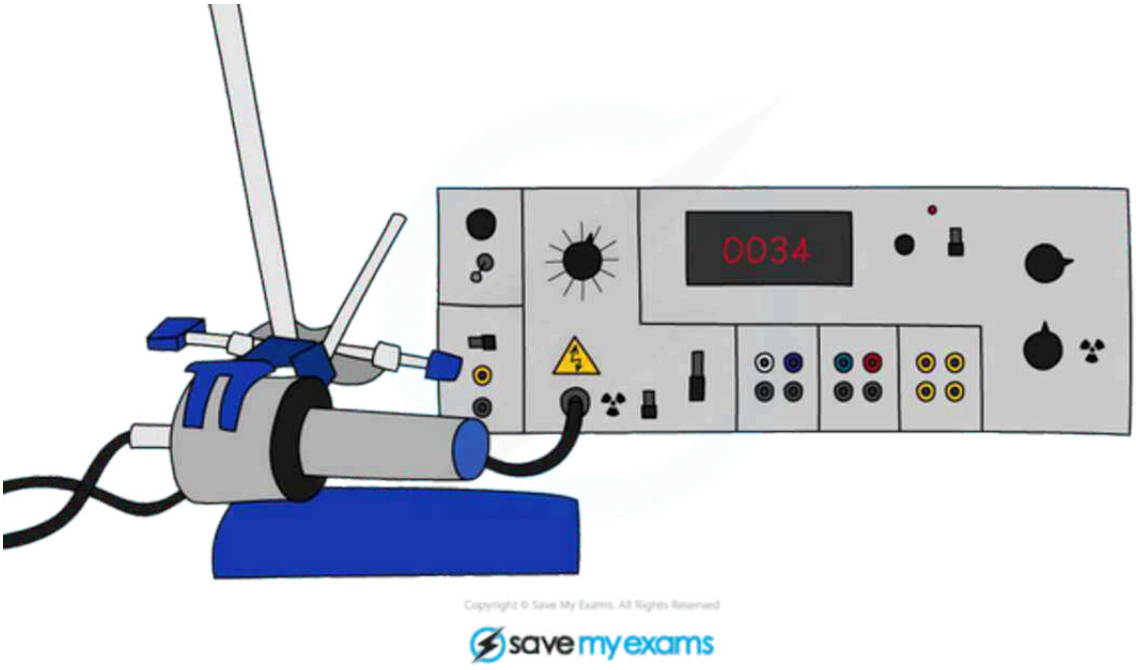
- The **Geiger-Müller tube** is the most common device used to measure and detect β-particles and γ-radiation
- Each time it absorbs radiation it transmits an electrical pulse to a counting machine called a **counter**
 - This makes a clicking sound or displays the **count rate** on a screen

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- The greater the frequency of clicks heard, or the higher the count rate seen, the more radiation the Geiger-Müller tube is absorbing
 - Therefore, it matters how close the tube is to the radiation source
 - The further away from the source, the lower the count rate detected

Your notes

A Geiger-Müller Counter



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A Geiger-Müller tube (or Geiger counter) is a common type of radiation detector

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Worked example

A Geiger-Müller tube is used to detect radiation in a particular location. If it counts 16,000 decays in 1 hour, what is the count rate?

Answer:

Step 1: Identify the different variables

- The number of decays is 16 000
- The time is 1 hour

Step 2: Determine the time period in seconds

- 1 hour is equal to 60 minutes, and 1 minute is equal to 60 seconds

$$\text{Time period} = 1 \times 60 \times 60 = 3600 \text{ seconds}$$

Step 3: Divide the total counts by the time period in seconds

$$\text{Counts} \div \text{Time period} = 16\,000 \div 3600 = 4.5$$

- Therefore, there are **4.5 decays per second**

Exam Tip

If asked to name a device for detecting radiation, the Geiger-Müller tube is a good example to give. You can also refer to it as a GM tube, a GM detector, GM counter, Geiger counter etc. (The examiners will allow some level of misspelling, providing it is readable). Don't, however, refer to it as a 'radiation detector' as this is too vague and may simply restate what was asked for in the question.

Your notes

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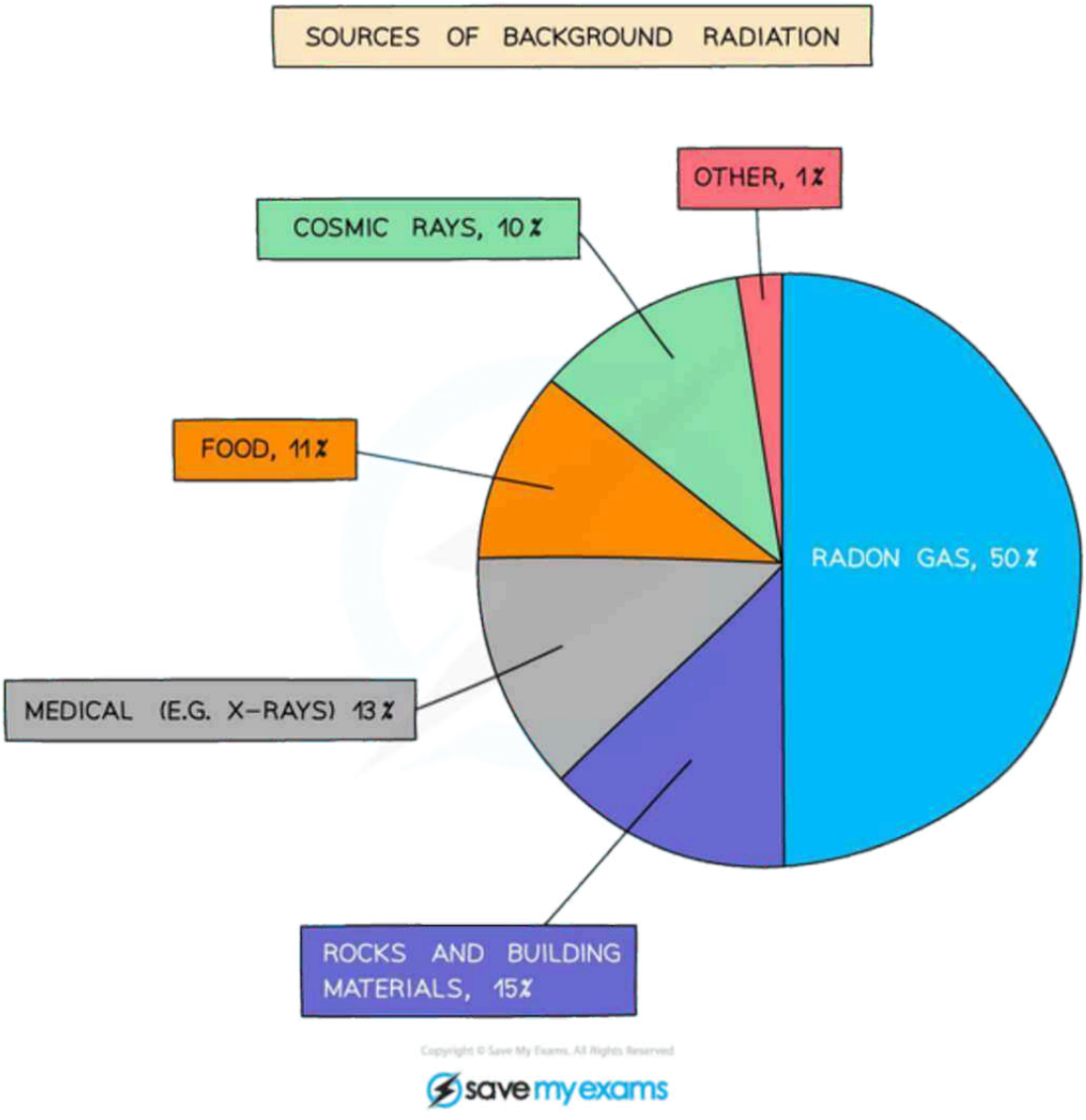
Background Radiation

Your notes

Background Radiation

- Background radiation is the radiation that is **always present** around us in the **environment**

A Pie Chart Showing Sources of Background Radiation



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Background radiation is the radiation that is present all around in the environment

- Although most background radiation is natural, a small amount of it comes from artificial sources, such as **medical procedures** (including X-rays)
- Levels of background radiation can vary significantly from place to place
 - Radiation from Nuclear Power come to less than 0.1% of the total


Your notes

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Sources of Background Radiation


Your notes

- Background radiation can come from **natural sources** on Earth or from space as well as **man-made sources**

Natural Sources

- **Radon gas (in the air)**
 - Airborne radon comes from the ground
 - This is from the natural decay of uranium in rocks and soil
 - The gas is tasteless, colourless and oderless but it not generally a health issue
- **Rocks and Buildings**
 - Heavy radioactive elements, such as uranium and thorium, occur naturally in rocks in the ground
 - Uranium decays into radon gas, which is an alpha emitter
 - This is particularly dangerous if inhaled into the lungs in large quantities
 - Natural radioactivity can be found in building materials, including decorative rocks, stone and brick
- **Cosmic rays from space**
 - The sun emits an enormous number of protons every second
 - Some of these enter the Earth's atmosphere at high speeds
 - When they collide with molecules in the air, this leads to the production of gamma radiation
 - Other sources of cosmic rays are supernovae and other high energy cosmic events
- **Carbon-14 in biological material**
 - All organic matter contains a tiny amount of carbon-14
 - Living plants and animals constantly replace the supply of carbon in their systems hence the amount of carbon-14 in the system stays almost constant
- **Radioactive material in food and drink**
 - Naturally occurring radioactive elements can get into food and water since they are in contact with rocks and soil containing these elements
 - Some foods contain higher amounts such as potassium-40 in bananas
 - However, the amount of radioactive material is minuscule and is not a cause for concern

Man-Made Sources

- **Medical sources**
 - In medicine, radiation is utilised all the time
 - Uses include X-rays, CT scans, radioactive tracers, and radiation therapy
- **Nuclear waste**
 - While nuclear waste itself does not contribute much to background radiation, it can be dangerous for the people handling it

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- **Nuclear fallout from nuclear weapons**
 - Fallout is the residue radioactive material that is thrown into the air after a nuclear explosion, such as the bomb that exploded at Hiroshima
 - While the amount of fallout in the environment is presently very low, it would increase significantly in areas where nuclear weapons are tested
- **Nuclear accidents**
 - Accidents such as that in Chernobyl contributed a large dose of radiation into the environment
 - While these accidents are now extremely rare, they can be catastrophic and render areas devastated for centuries


Your notes

Exam Tip

The sources that make the most significant contribution are the natural sources:

- Radon gas
- Rocks and buildings
- Food and drink
- Cosmic rays

Make sure you remember these for your exam!

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Accounting for Background Radiation


Your notes

- Background radiation must be accounted for when taking readings in a laboratory
- This can be done by taking readings with no radioactive source present and then subtracting this from readings with the source present
 - This is known as the **corrected count rate**

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Your notes

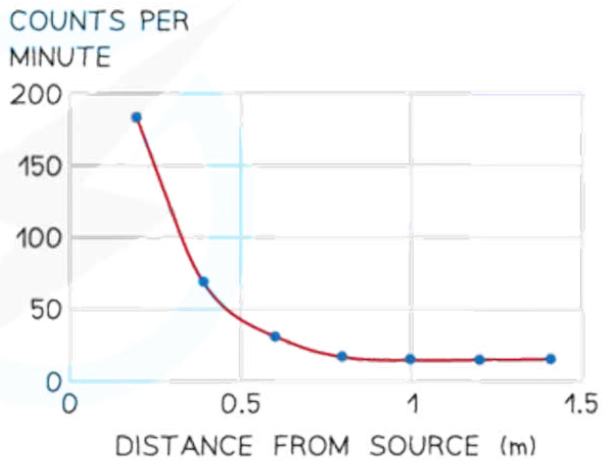
Worked example

A student is using a Geiger-counter to measure the counts per minute at different distances from a source of radiation. Their results and a graph of the results are shown here.

RESULTS TABLE

Distance from source (m)	Counts per minute
0.2	180
0.4	67
0.6	29
0.8	17
1.0	15
1.2	15
1.4	15

GRAPH



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Determine the background radiation count.

Answer:

Step 1: Determine the point at which the source radiation stops being detected

- The background radiation is the amount of radiation received all the time
- When the source is moved back far enough it is all absorbed by the air before reaching the Geiger-counter
- Results after 1 metre do not change
- Therefore, the amount after 1 metre is only due to background radiation

Step 2: State the background radiation count

- The background radiation count is **15 counts per minute**

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Your notes

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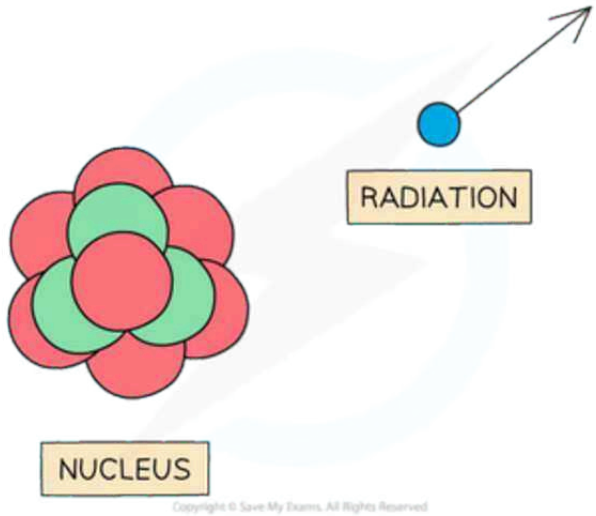
The Three Types of Emission

Your notes

Emission of Radiation from a Nucleus

- Unstable nuclei can emit radiation to become more stable
- Radiation can be in the form of a high-energy particle or wave
- The process of emitting radiation is called **radioactive decay**

Radioactive Decay



Unstable nuclei decay by emitting high-energy particles or waves

- As the radiation moves away from the nucleus, it takes some energy with it
 - This reduces the overall energy of the nucleus
 - This makes the nucleus more **stable**
- Radioactive decay is a **spontaneous** and **random** process
- A random process means:

 It is not possible to know exactly when, or in which direction, a particular nucleus will decay

- A spontaneous process means:

 Radioactive decay cannot be affected by environmental factors such as temperature, pressure, or chemical conditions

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Types of Radioactive Decay

Your notes

- When an unstable nucleus decays, it emits radiation called **nuclear radiation**
- There are different types of radiation that can be emitted:
 - **Alpha (α)** particles
 - **Beta (β^-)** particles
 - **Gamma (γ)** radiation
- These changes are **spontaneous** and **random**

Alpha Particles

- The symbol for alpha is **α**
- An alpha particle is the same as a helium nucleus
 - This is because they consist of two neutrons and two protons
- Alpha particles have a charge of +2
 - This means they can be affected by an electric field

Beta Particles

- The symbol for beta is **β^-**
- Beta particles are fast-moving electrons
- They are produced in nuclei when a neutron changes into a proton and an electron
- Beta particles have a charge of -1
 - This means they can be affected by an electric field

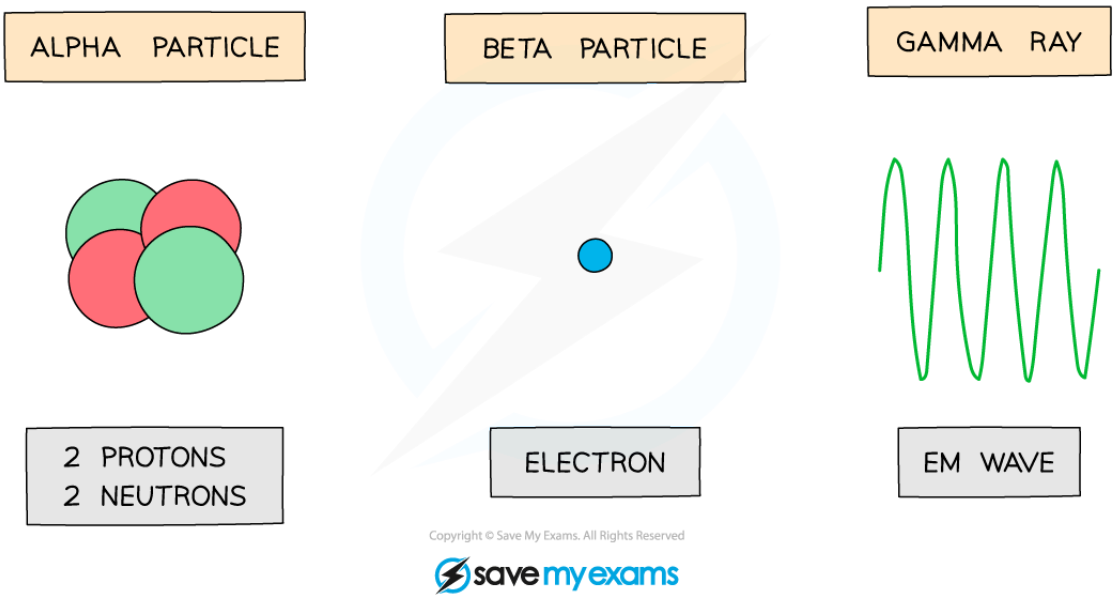
Gamma Rays

- The symbol for gamma is **γ**
- Gamma rays are electromagnetic waves
- They have the highest energy of the different types of electromagnetic waves
- Gamma rays have no charge

Alpha Particles, Beta Particles and Gamma Rays

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Your notes



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Alpha particles, beta particles and gamma waves can be emitted from unstable nuclei

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Alpha, Beta & Gamma Emission

Your notes

- α, β and γ radiation can be identified by the emission from a nucleus by recalling their:
 - Nature (what type of particle or radiation they are)
 - Their relative ionising effects (how easily they ionise other atoms)
 - Their relative penetrating abilities (how far can they travel before they are stopped completely)
- The properties of alpha, beta and gamma are given in this table and then described in more detail

Different Properties of Nuclear Radiation

Particle	What is it	Charge	Range in Air	Penetration	Ionisation
Alpha (α)	2 protons + 2 neutrons	+2	Few cm	Stopped by Paper	High
Beta (β^-)	Electron	−1	A few tens of cm	Stopped by a few mm of Aluminium	Medium
Gamma (γ)	Electromagnetic Wave	0	Infinite	Reduced by a Few mm Lead	Low

- The trend down the table shows:
 - The range increases
 - Penetrating power increases
 - Ionisation decreases

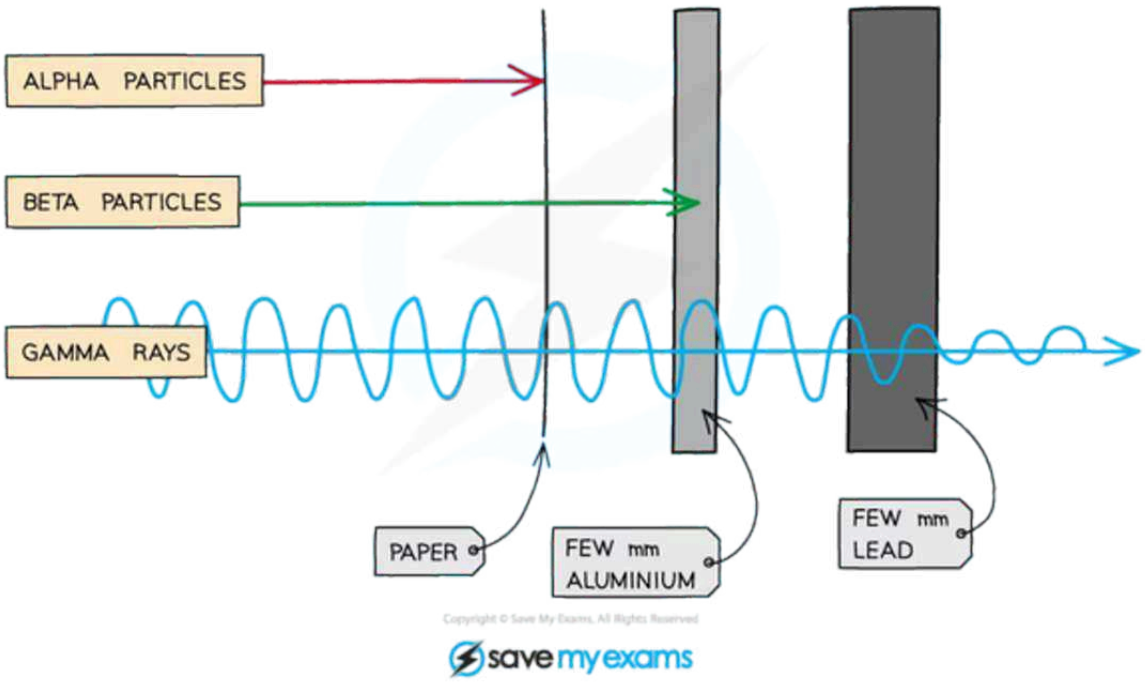
Penetrating Power

- Alpha, beta and gamma radiation **penetrate** materials in different ways
 - This means they are stopped by different materials

Penetrating Power of Alpha, Beta and Gamma Radiation

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Your notes



Alpha, beta and gamma are different in how they penetrate materials. Alpha is the least penetrating, and gamma is the most penetrating

- Alpha is stopped by **paper**, whereas beta and gamma pass through it
- Beta is stopped by a few millimetres of aluminium
 - Gamma can pass through **aluminium**
- Gamma rays are only partially stopped by thick **lead**

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Worked example

A student has an unknown radioactive source.

They are trying to work out which type of radiation is being emitted.

The student measures the count rate using a Geiger-Muller tube when the source is placed behind different materials. They record their results in a table.

	no material	thin paper	5 mm aluminium	5 mm lead
Count rate / counts per minute	4320	4218	256	134

Which type of radiation is being given off by the source?

A Alpha particles

B Beta particles

C Gamma rays

D Neutrons

ANSWER: B

- The thin paper did not decrease the count rate significantly, but the aluminium (and lead) did
- Therefore, the source must be **beta** particles, which is option **B**
- The answer is **not A** because the radiation passed through the paper almost unchanged, therefore it is **not** alpha radiation
- The answer is **not C** because even though the lead decreased the count rate significantly, the aluminium did too, therefore it is **not** gamma radiation (as gamma penetrates aluminium)
- The answer is **not D** because a Geiger counter does not detect neutrons

Exam Tip

Remembering the type of particle, penetration and ionising power for alpha, beta and gamma radiation is very important for your exam! Often the exam question will give some clues and you will have to choose which type of radiation it could be based off these.

Your notes

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Deflection in Electric & Magnetic Fields

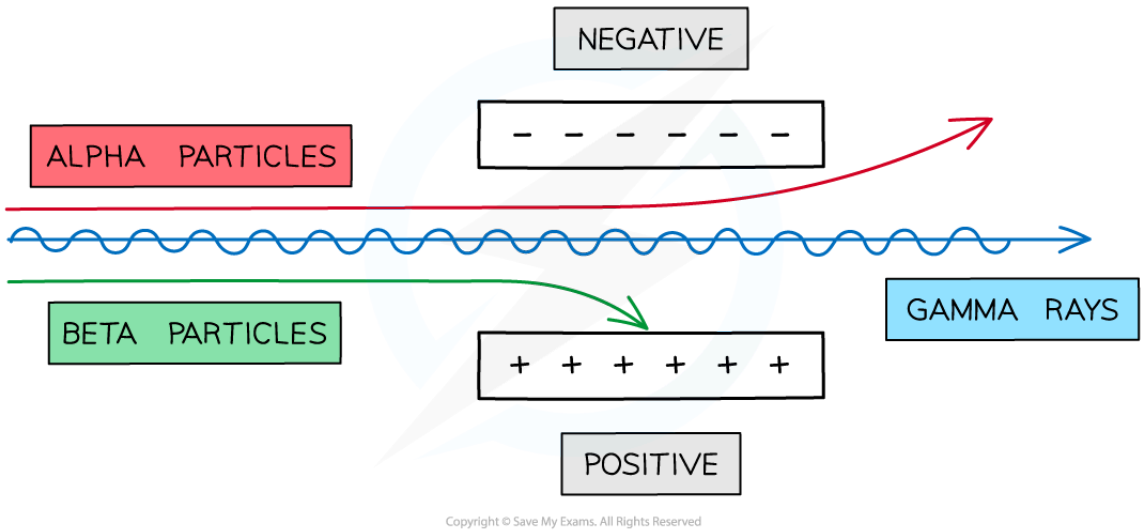
Your notes

- A particle is deflected in an electric field if it has **charge**
- A particle is deflected in a magnetic field if it has **charge** and is **moving** perpendicular to it
 - Therefore, since gamma (γ) particles have no charge, they are **not** deflected by either electric or magnetic fields
 - Only alpha (α) and beta (β) particles are

Electric Fields

- Alpha particles have a **charge of +2** (charge of a helium nucleus)
- Beta particles have a **charge of −1** (charge of an electron)
- Therefore, between an electric field created between a negatively charged and positively charged plate
 - Alpha particles are deflected towards the **negative** plate
 - Beta particles are deflected towards the **positive** plate
 - Gamma radiation is not deflected and travels straight through between the plates

The Deflection of Alpha, Beta and Gamma Particles in a Magnetic Field



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Alpha and Beta particles can be deflected by electric fields

- Alpha particles are **heavier** than beta particles
 - Therefore, beta particles are deflected more in the electric field and alpha is deflected less

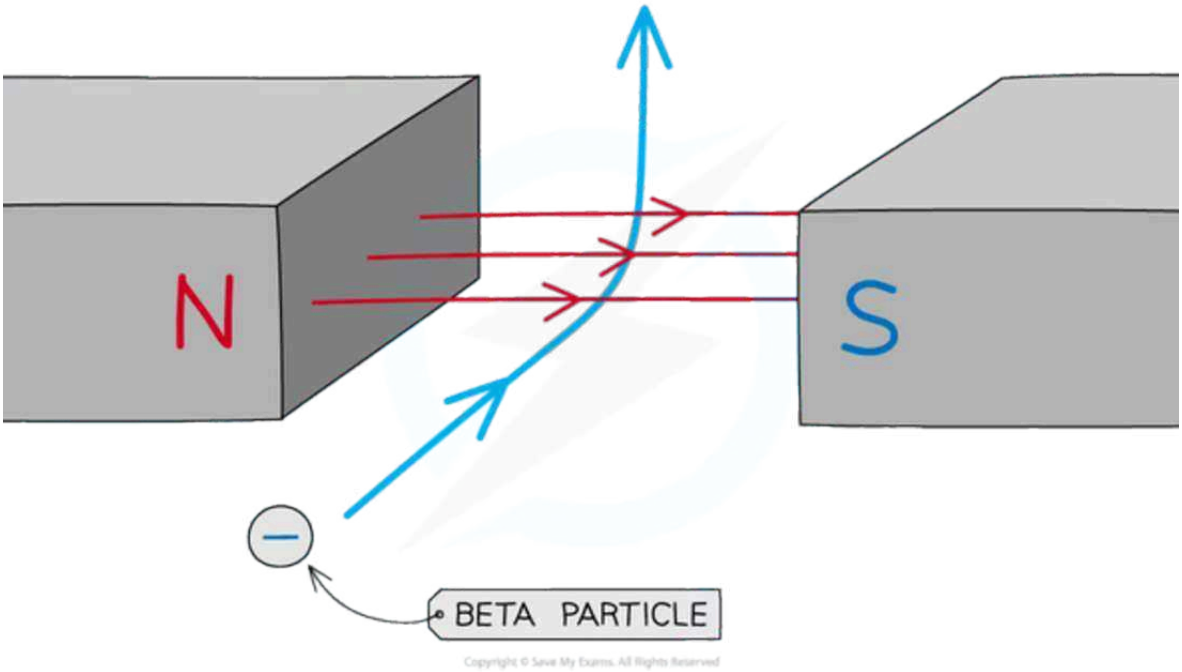
Magnetic Fields

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- Similarly, alpha and beta particles are deflected by magnetic fields whilst they are moving
- They are deflected in **opposite** directions due to their opposite charges

Your notes

The Deflection of a Beta Particle in a Magnetic Field



Alpha and Beta particles can also be deflected by magnetic fields

Exam Tip

It is important to note that because of their opposite charges, alpha and beta particles will deflect in **opposite** directions. You do not need to know which direction alpha and beta particles are deflected in a magnetic field but you should know that they are deflected, whilst gamma is not because they are charged and they deflect in opposite directions.

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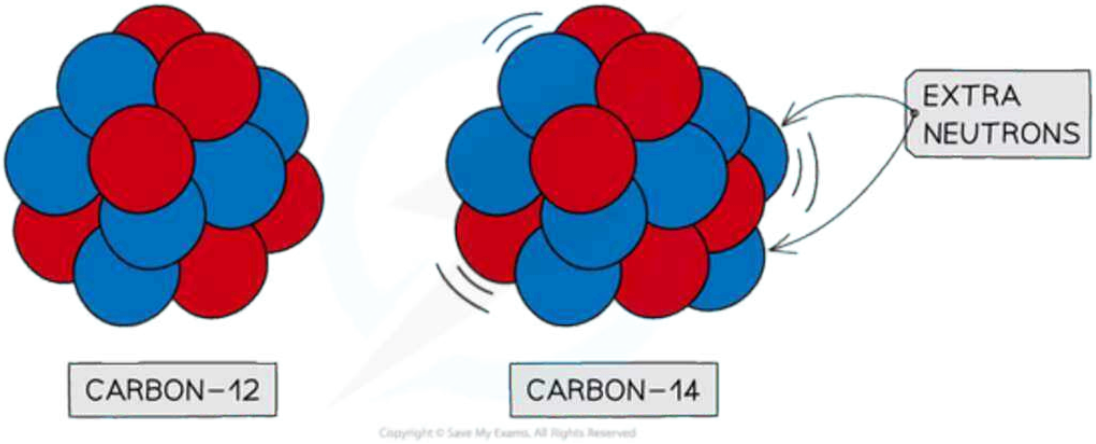
Radioactive Decay

Your notes

Radioactive Decay

- Some atomic nuclei are **unstable**
- This is because of an imbalance in the forces within the nucleus
 - Forces exist between the particles in the nucleus
 - This is commonly due to the nucleus having too many protons or neutrons
- Carbon-14 is an isotope of carbon which is **unstable**
 - It has two extra neutrons compared to stable carbon-12

Isotopes of Carbon-12 and Carbon-14



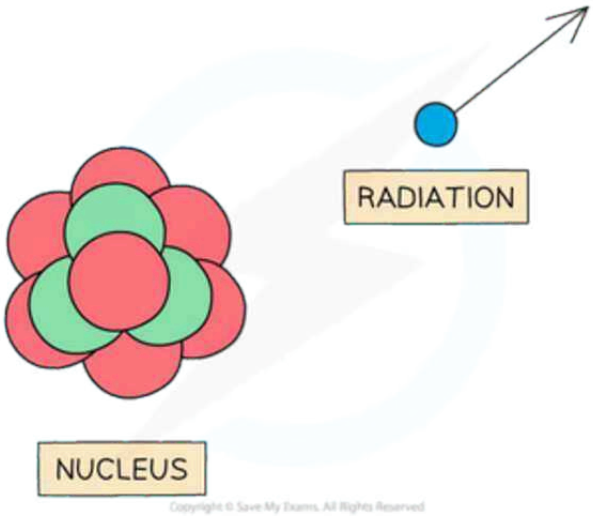
Carbon-12 is stable, whereas carbon-14 is unstable. This is because carbon-14 has two extra neutrons

- Some isotopes are unstable because of their large size or because they have too many or too few neutrons
- Unstable nuclei can **emit radiation** in the form of **α-particles** to become more stable

An Unstable Nucleus Emitting an Alpha Particle

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Your notes



Unstable nuclei decay by emitting α-particles

- As the α-particle moves away from the nucleus, it takes some energy with it
 - This reduces the overall energy of the nucleus
 - It makes the nucleus more **stable**
- The process of emitting α-particles is called **radioactive decay**
- Radioactive decay is a **random** process
 - There is an **equal probability** of any nucleus decaying
 - It cannot be known **which particular nucleus will decay next**
 - It cannot be known **at what time a particular nucleus will decay**
 - The rate of decay is **unaffected** by the surrounding conditions
 - It is only possible to estimate the **probability** of a nucleus decaying in a given time-period
- Therefore, the emission of radiation is:
 - **Spontaneous**
 - **Random in direction**

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Worked example

Which of the following statements is **not** true?

A Isotopes can be unstable because they have too many or too few neutrons

B The process of emitting particles or waves of energy from an unstable nucleus is called radioactive decay

C Scientists can predict when a nucleus will decay

D Radiation refers to the particles or waves emitted from a decaying nucleus

ANSWER: C

- Answer A is **true.** The number of neutrons in a nucleus determines the stability
- Answer B is **true.** This is a suitable description of radioactive decay
- Answer D is **true.** Radiation is about emissions. It is different to radioactive particles
- Answer C is **not true**
 - Radioactive decay is a random process
 - It is not possible to predict precisely when a particular nucleus will decay

Exam Tip

The terms **unstable**, **random** and **decay** have very particular meanings in this topic. Remember to use them correctly when answering questions!


Your notes

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Decay Equations

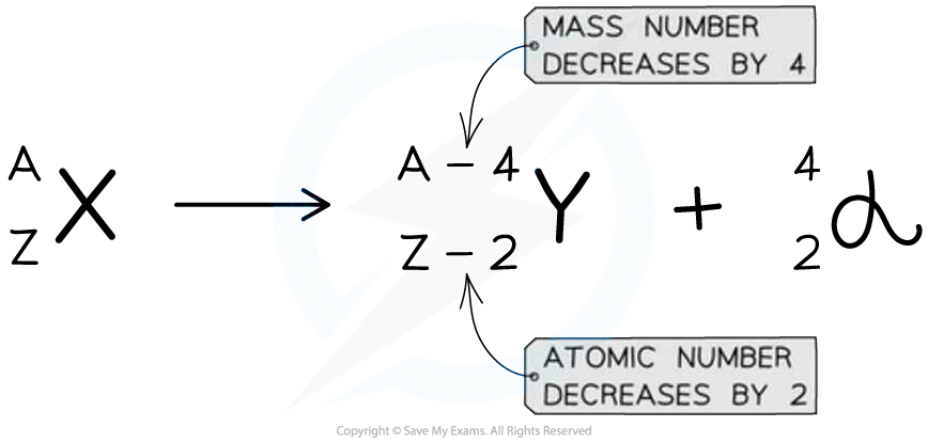
Your notes

- Radioactive decay events can be shown using a **decay equation**
- A decay equation is similar to a chemical reaction equation
 - The particles present before the decay are shown **before** the arrow
 - The particles produced in the decay are shown **after** the arrow
- During decay equations, the sum of the mass and atomic numbers **before** the reaction must be the same as the sum of the mass and atomic numbers **after** the reaction

Alpha Decay Equations

- When the alpha particle is emitted from the unstable nucleus, the mass number and atomic number of the nucleus changes
 - The mass number **decreases** by 4
 - The atomic number **decreases** by 2

The Alpha Decay Equation



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Alpha decay equation showing the change in mass and atomic numbers

- The following decay equation shows Polonium-212 undergoing alpha decay
 - It forms Lead-208 and an alpha particle
 - An alpha particle can also be written as a helium nucleus (Symbol He)

$$\text{e.g. } {}^{212}_{84}\text{Po} \rightarrow {}^{208}_{82}\text{Pb} + {}^{4}_{2}\alpha$$

Beta Decay Equation

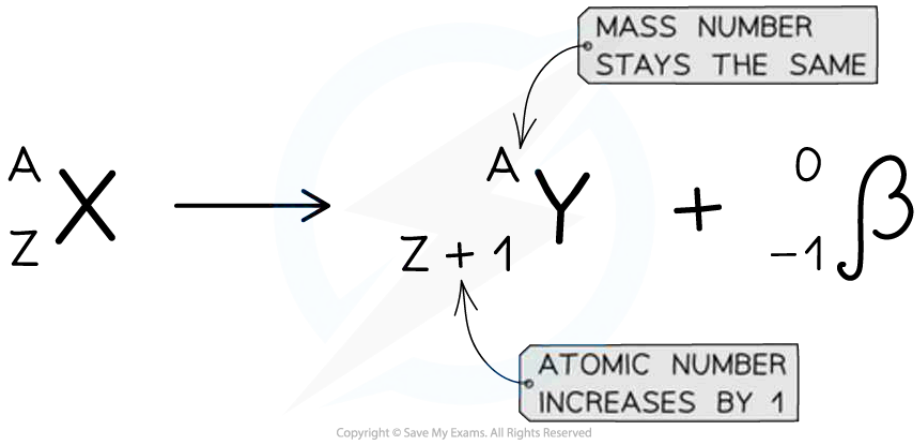
- During **beta** decay, a **neutron** changes into a **proton** and an **electron**

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- The electron is **emitted** and the proton **remains** in the nuclei

Your notes

The Beta Decay Equation

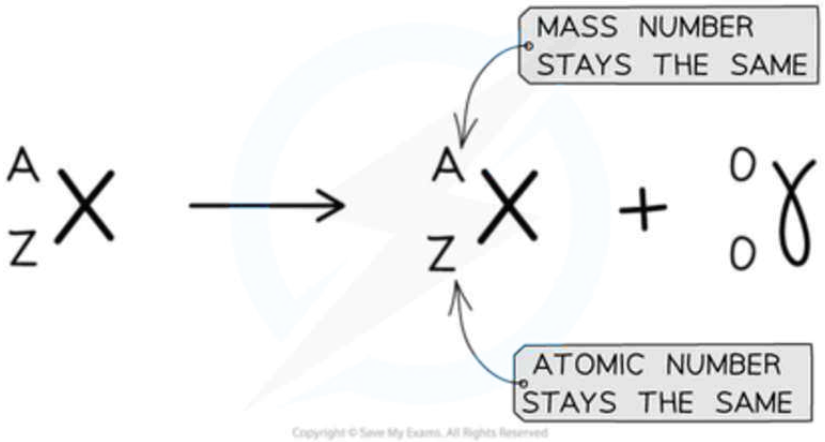


Beta decay equation showing the change in atomic number

Gamma Decay

- The gamma ray that is emitted has a lot of energy, but no mass or charge
- Here is an example of Uranium-238 undergoing gamma decay
 - Notice that the mass number and atomic number of the unstable nuclei remain the same during the decay

The Gamma Decay Equation



Gamma decay equation showing no change in mass or atomic number

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Worked example

A nucleus with 84 protons and 126 neutrons undergoes alpha decay. It forms lead, which has the element symbol Pb.

A $^{206}_{82}Pb$

B $^{208}_{82}Pb$

C $^{210}_{84}Pb$

D $^{214}_{86}Pb$

Which of the isotopes of lead listed is the correct one formed during the decay?

ANSWER: A

Step 1: Calculate the mass number of the original nucleus

- The mass number is equal to the number of protons plus the number of neutrons
- The original nucleus has 84 protons and 126 neutrons

$$84 + 126 = 210$$

- The mass number of the original nucleus is 210

Step 2: Calculate the new atomic number

- The alpha particle emitted is made of two protons and two neutrons
- Protons have an atomic number of 1, and neutrons have an atomic number of 0
- Removing two protons and two neutrons will reduce the atomic number by 2

$$84 - 2 = 82$$

- The new nucleus has an atomic number of **82**

Step 3: Calculate the new mass number

- Protons and neutrons both have a mass number of 1
- Removing two protons and two neutrons will reduce the mass number by 4

$$210 - 4 = 206$$

Your notes

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- The new nucleus has a mass number of **206**

Your notes

Worked example

A nucleus with 11 protons and 13 neutrons undergoes beta decay. It forms magnesium, which has the element symbol Mg.

A $^{20}_{9}Mg$ B $^{24}_{10}Mg$ C $^{23}_{11}Mg$ D $^{24}_{12}Mg$

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Which is the correct isotope of magnesium formed during the decay?

ANSWER: D

Step 1: Calculate the mass number of the original nucleus

- The mass number is equal to the number of protons plus the number of neutrons
- The original nucleus has 11 protons and 13 neutrons

$$11 + 13 = 24$$

- The mass number of the original nucleus is 24

Step 2: Calculate the new atomic number

- During beta decay a neutron changes into a proton and an electron
- The electron is emitted as a beta particle
- The neutron has an atomic number of 0 and the proton has an atomic number of 1
- So the atomic number increases by 1

$$11 + 1 = 12$$

- The new nucleus has an atomic number of 12

Step 3: Calculate the new mass number

- Protons and neutrons both have a mass number of 1
- Changing a neutron to a proton will not affect the mass number
- The new nucleus has a mass number of 24 (the same as before)

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Exam Tip

You are not expected to know the names of the elements produced during radioactive decays, but you do need to be able to calculate the mass and atomic numbers by making sure they are balanced on either side of the reaction.



Your notes

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Fission & Fusion


Your notes

Fission & Fusion

- Nuclei can join together, or split up, to form new nuclei
- These processes are known are
 - Nuclear fission
 - Nuclear fusion

Nuclear Fission

- There is a lot of energy stored within the nucleus of an atom
 - This energy can be released in a nuclear reaction such as **fission**
- Nuclear fission is defined as:

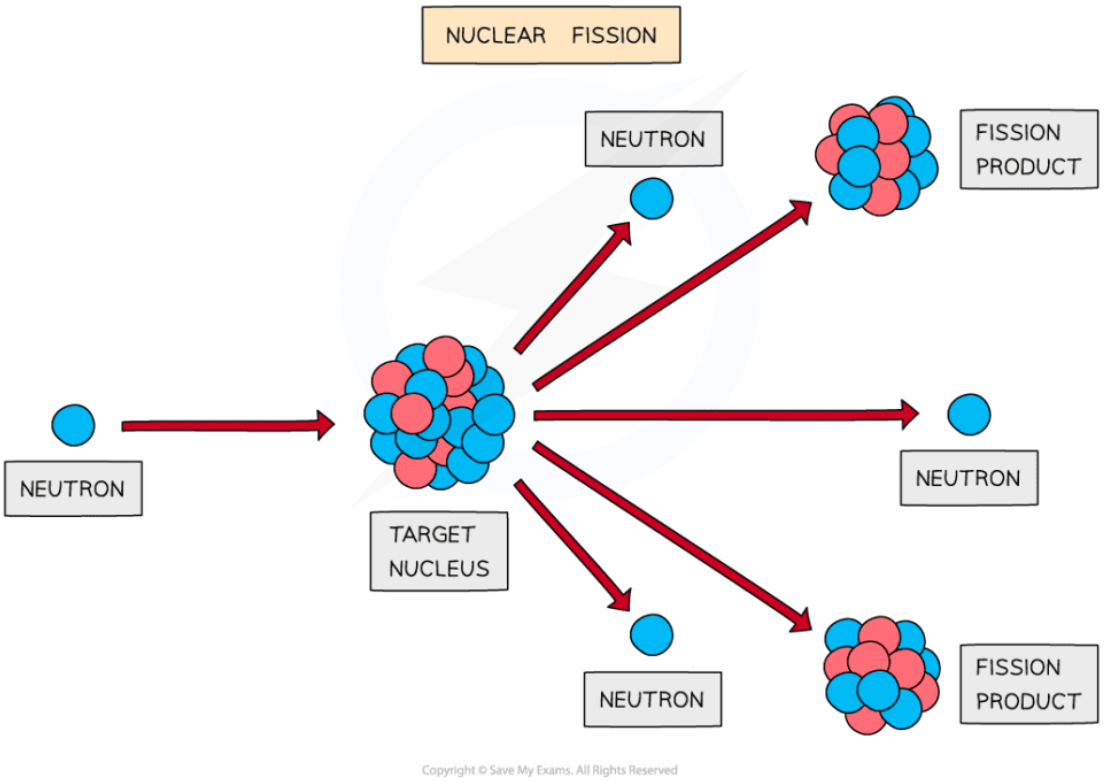
 The splitting of a large, unstable nucleus into two smaller nuclei

- Isotopes of **uranium** and **plutonium** both undergo fission and are used as fuels in nuclear power stations
- During fission, when a neutron collides with an unstable nucleus, the nucleus splits into **two smaller nuclei** (called daughter nuclei) as well as **two or three neutrons**
 - Gamma rays are also emitted

How does nuclear fission work?

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Your notes



A neutron is fired into the target nucleus, causing it to split into two smaller nuclei

- The products of fission move away very **quickly**
 - Energy transferred is from **nuclear potential energy** to kinetic energy
- The mass of the products (daughter nuclei and neutrons) is **less** than the mass of the original nucleus
 - This is because the remaining mass has been converted into **energy** which is released during the fission process

Nuclear Fusion

- Small nuclei can react to release energy in a process called **nuclear fusion**
- Nuclear fusion is defined as:

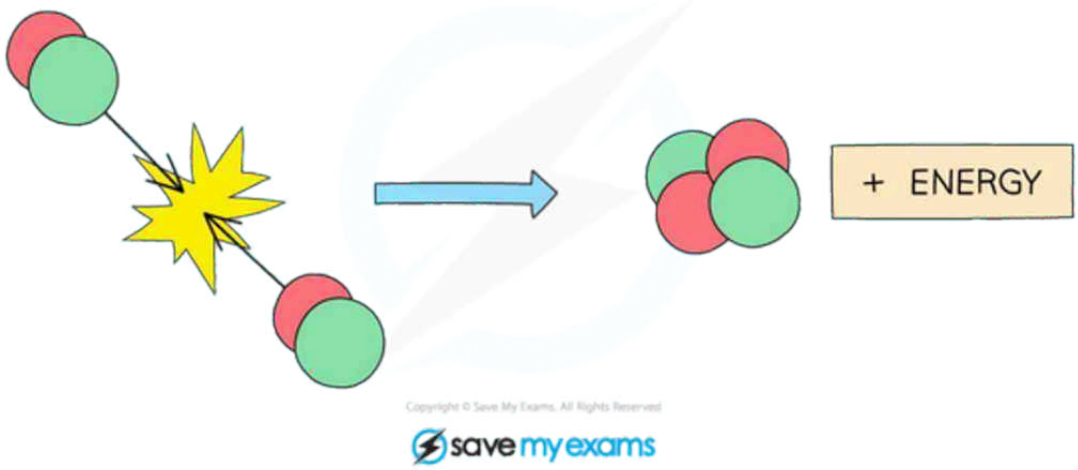
 When two light nuclei join to form a heavier nucleus

- This process requires extremely **high temperatures** to maintain
 - This is why nuclear fusion has proven very hard to reproduce on Earth
- Stars use nuclear fusion to produce energy
- In most stars, hydrogen atoms are fused together to form helium and produce lots of energy

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How does nuclear fusion work?

Your notes



Two hydrogen nuclei are fusing to form a helium nuclei

- The energy produced during nuclear fusion comes from a very small amount of the particle's mass being **converted** into energy
- Albert Einstein described the mass-energy equivalence with his famous equation:

$$E = mc^2$$

- Where:
 - E = energy released from fusion in Joules (J)
 - m = mass converted into energy in kilograms (kg)
 - c = the speed of light in metres per second (m/s)
- Therefore, the mass of the product (fused nucleus) is **less** than the mass of the two original nuclei
 - This is because the remaining mass has been converted into **energy** which is released when the nuclei fuse
- The amount of energy released during nuclear fusion is huge:
 - The energy from 1 kg of hydrogen that undergoes fusion is equivalent to the energy from burning about 10 million kilograms of coal
- An example of a nuclide equation for fusion is:

$${}^{2}_{1}H + {}^{1}_{1}H \rightarrow {}^{3}_{2}\mathrm{He} + \text{energy}$$

- Where:
 - ${}^{2}_{1}\mathrm{H}$ is deuterium (isotope of hydrogen with 1 proton and 1 neutron)
 - ${}^{1}_{1}\mathrm{H}$ is hydrogen (with one proton)

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- $^{3}_{2}He$ is an isotope with helium (with two protons and one neutron)

Your notes

Worked example

The nuclear equation for a fission reaction is



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Calculate the number of neutrons *N* emitted in this reaction.

Answer:

Step 1: Calculate the nucleon number on the left side of the equation

LHS: $235 + 1 = 236$

Step 2: Calculate the nucleon number on the right side of the equation

RHS: $96 + 138 + N = 233 + N$

Step 3: Equate the nucleon number for both sides of the equation

LHS = RHS

$236 = 233 + N$

Step 4: Rearrange for the number of neutrons N

$N = 236 - 233 = 3$

- Therefore, **3 neutrons** are produced in this fission reaction

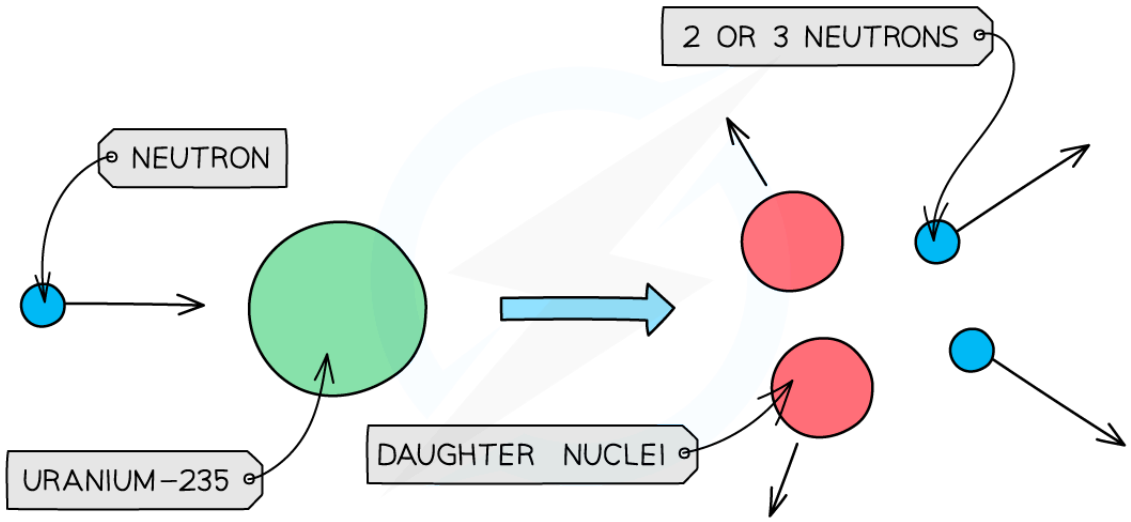
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Fission Reactions

Your notes

- The processes involved in nuclear fission can be shown in different ways, such as diagrams and nuclear equations

Fission of Uranium-235



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Large nuclei can decay by fission to produce smaller nuclei and neutrons with a lot of kinetic energy

- The diagram above is useful because it shows clearly the different parts of the fission reaction
- An example of a nuclide equation for fission is:

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{92}_{36}\mathrm{Kr} + {}^{141}_{56}\mathrm{Ba} + 3\,{}^{1}_{0}\mathrm{n} + \text{energy}$$

- Where:
 - $^{235}_{92}\mathrm{U}$ is an unstable isotope of Uranium
 - $^{1}_{0}\mathrm{n}$ is a neutron
 - $^{92}_{36}\mathrm{Kr}$ us an unstable isotope of Krypton
 - $^{141}_{56}\mathrm{Ba}$ is an unstable isotope of Barium
- This equation represents a fission reaction in which
 - A Uranium-235 nucleus is hit by a neutron
 - It splits into two smaller nuclei – a Krypton nucleus and a Barium nucleus
 - Three neutrons are released in the process which can go on to trigger further fission reactions

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- The sum of the top (nucleon) numbers on the left-hand side equals the sum of top number on the right-hand side:

$$235 + 1 = 92 + 141 + (3 \times 1)$$

- The same is true for the lower (proton) numbers:

$$92 + 0 = 36 + 56 + (2 \times 0)$$

Your notes

Worked example

The nuclear equation for a fission reaction is



Calculate the number of neutrons *N* emitted in this reaction.

Answer:

Step 1: Calculate the nucleon number on the left side of the equation

LHS: $235 + 1 = 236$

Step 2: Calculate the nucleon number on the right side of the equation

RHS: $96 + 138 + N = 233 + N$

Step 3: Equate the nucleon number for both sides of the equation

LHS = RHS

$236 = 233 + N$

Step 4: Rearrange for the number of neutrons N

$N = 236 - 233 = 3$

- Therefore, **3 neutrons** are produced in this fission reaction

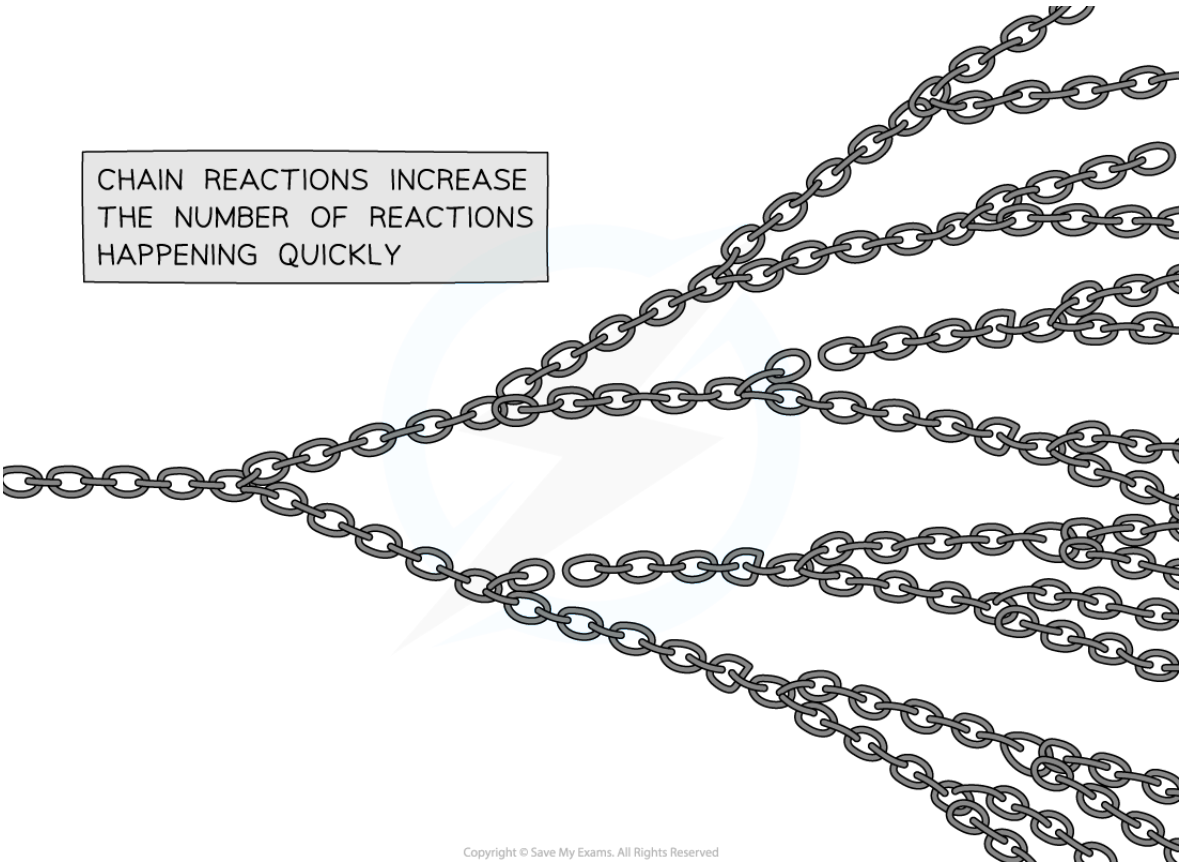
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Chain Reactions

Your notes

- Only one extra neutron is required to induce a Uranium-235 nucleus to split by fission
- During the fission, it produces two or three neutrons which move away at high speed
- Each of these new neutrons can start another fission reaction, which again creates further **excess neutrons**
- This process is called a **chain reaction**

Chain Reaction Analogy



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The neutrons released by each fission reaction can go on to create further fissions, like a chain that is linked several times – from each chain comes two more

Controlled Chain Reactions

- In a nuclear reactor, a chain reaction is required to keep the reactor running
- When the reactor is producing energy at the correct rate, the number of free neutrons in the reactor needs to be kept constant
 - This means some must be removed from the reactor

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- To do this, nuclear reactors contain **control rods**
- These absorb neutrons without becoming dangerously unstable themselves


Your notes

Uncontrolled Chain Reactions

- Because each new fission reaction releases energy, uncontrolled chain reactions can be dangerous
- The number of neutrons available increases quickly, so the number of reactions does too
- A **nuclear weapon** uses an uncontrolled chain reaction to release a huge amount of energy in a short period of time as an explosion

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Half-Life

Your notes

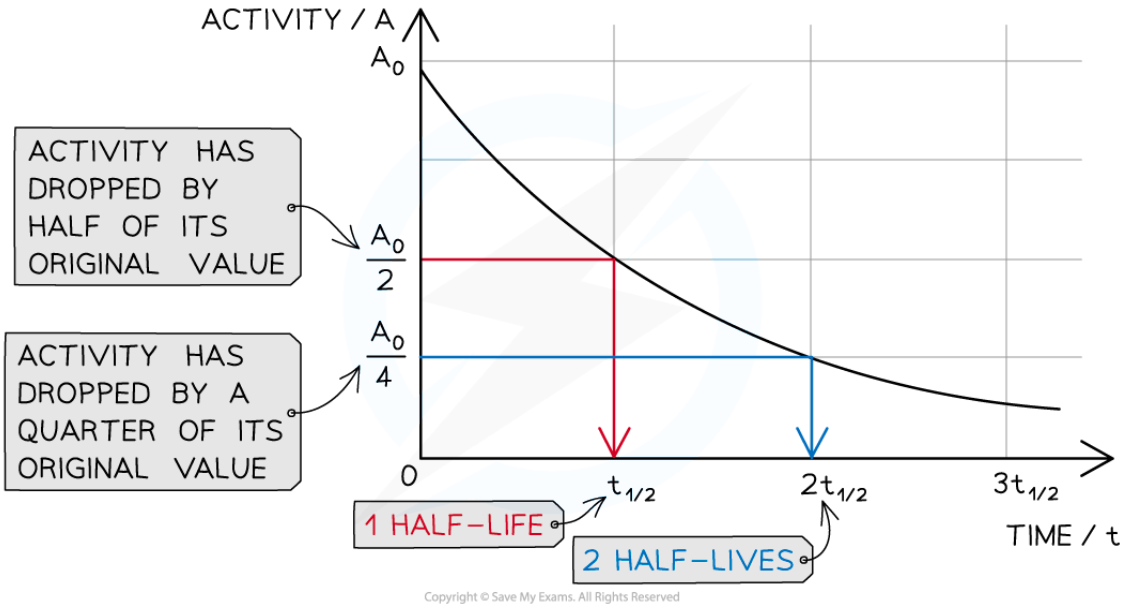
Half-Life Basics

- It is impossible to know when a particular unstable nucleus will decay
- But the **rate** at which the activity of a sample decreases can be known
 - This is known as the **half-life**
- Half-life is defined as:

The time taken for half the nuclei of that isotope in any sample to decay

- In other words, the time it takes for the activity of a sample to fall to half its original level
- Different isotopes have different half-lives and half-lives can vary from a fraction of a second to billions of years in length
- Half-life can be determined from an activity-time graph

How to Determine Half-Life



The graph shows how the activity of a radioactive sample changes over time. Each time the original activity halves, another half-life has passed

- The time it takes for the activity of the sample to decrease from 100 % to 50 % is the half-life
 - It is the same length of time as it would take to decrease from 50 % activity to 25 % activity
 - The half-life is **constant** for a particular isotope
- The table below shows that

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- As the number of half-lives increases by 1, the proportion of the isotope remaining **halves**

Relationship between the number of half-lives to the proportion of isotope remaining

Number of half-lives	Proportion of isotope remaining
0	1
1	$\frac{1}{2}$
2	$\frac{1}{4}$
3	$\frac{1}{8}$
4	$\frac{1}{16}$


Your notes

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Dating of Objects Using C-14

Your notes

- The isotope **carbon-14** is commonly used in radioactive dating due to its abundance in living tissue
- Carbon-14 forms when a high-energy cosmic ray knocks a neutron out of a nucleus, which then collides with a nitrogen nucleus in the air
- This process can be represented by the equation:

$$^{1}_{0}n + ^{14}_{7}N \rightarrow ^{14}_{6}C + ^{1}_{1}p$$

- Plants take in carbon dioxide from the atmosphere for photosynthesis, including the radioactive isotope carbon-14
- Animals and humans take in carbon-14 by eating the plants
 - Therefore, **all living organisms** absorb carbon-14, but after they die they do not absorb any more
- The proportion of carbon-14 is **constant** in living organisms as carbon is constantly being replaced during the period they are alive
- When an organism dies, the activity of carbon-14 in the organic matter starts to **fall**, with a half-life of around 5730 years
- Samples of living material can be tested by measuring the current amount of carbon-14 it contains and comparing this to the initial amount (which is based on the current ratio of carbon-14 to carbon-12)
 - The proportion of carbon-14 a sample contains can therefore provide an approximate age for the sample

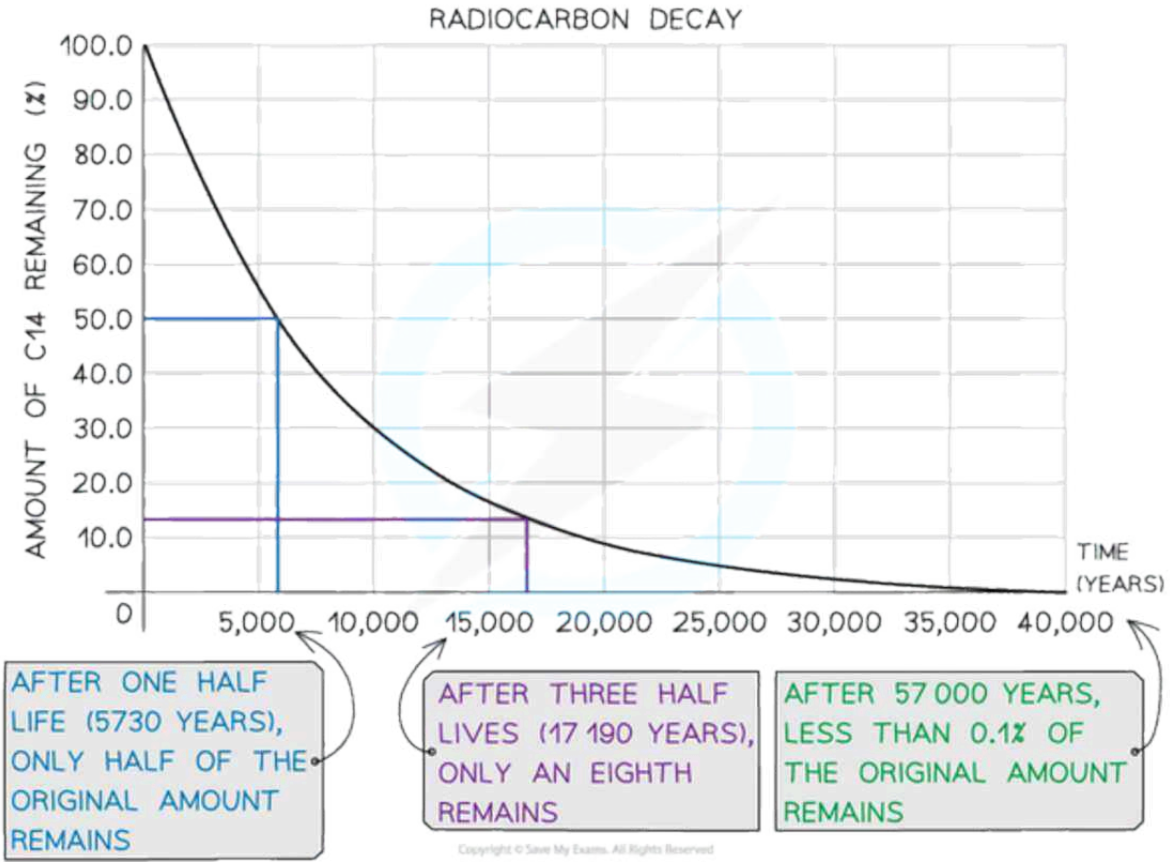
Reliability of Carbon Dating

- Carbon dating is a highly reliable ageing method for samples ranging from around 1000 to 40 000 years old
 - Therefore, for very **young**, or very **old** samples, carbon dating is not the most reliable method to use
- This can be explained by looking at the decay curve of carbon-14:

Decay Curve for Carbon-14

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Your notes



Carbon-14 decay curve used for carbon dating

- If the sample is **less than** 1000 years old:
 - The activity of the sample will be too high
 - So, it is difficult to accurately measure the small change in activity
 - Therefore, the ratio of carbon-14 to carbon-12 will be too high to determine an accurate age
- If the sample is **more than** 40 000 years old:
 - The activity will be too small and have a count rate similar to that of background radiation
 - So, there will be very few carbon-14 atoms remaining, hence very few decays will occur
 - Therefore, the ratio of carbon-14 to carbon-12 will be too small to determine an accurate age
- Carbon dating uses the currently known ratio of carbon-14 to carbon-12, however, scientists cannot know the level of carbon-14 in the biosphere thousands of years ago
- Therefore, this makes it difficult to age samples which are very old

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Uses of Radiation


Your notes

Uses of Radiation

- Radiation is used in a number of different ways, for example:
 1. Medical procedures (including diagnosis and treatment of cancer)
 2. Sterilising food (irradiating food to kill bacteria)
 3. Sterilising medical equipment (using gamma rays)
 4. Determining the age of ancient artefacts
 5. Measuring and controlling the thickness of materials
 6. Household fire (smoke) detectors
- The properties of the different types of radiation determine which one is used in a particular application

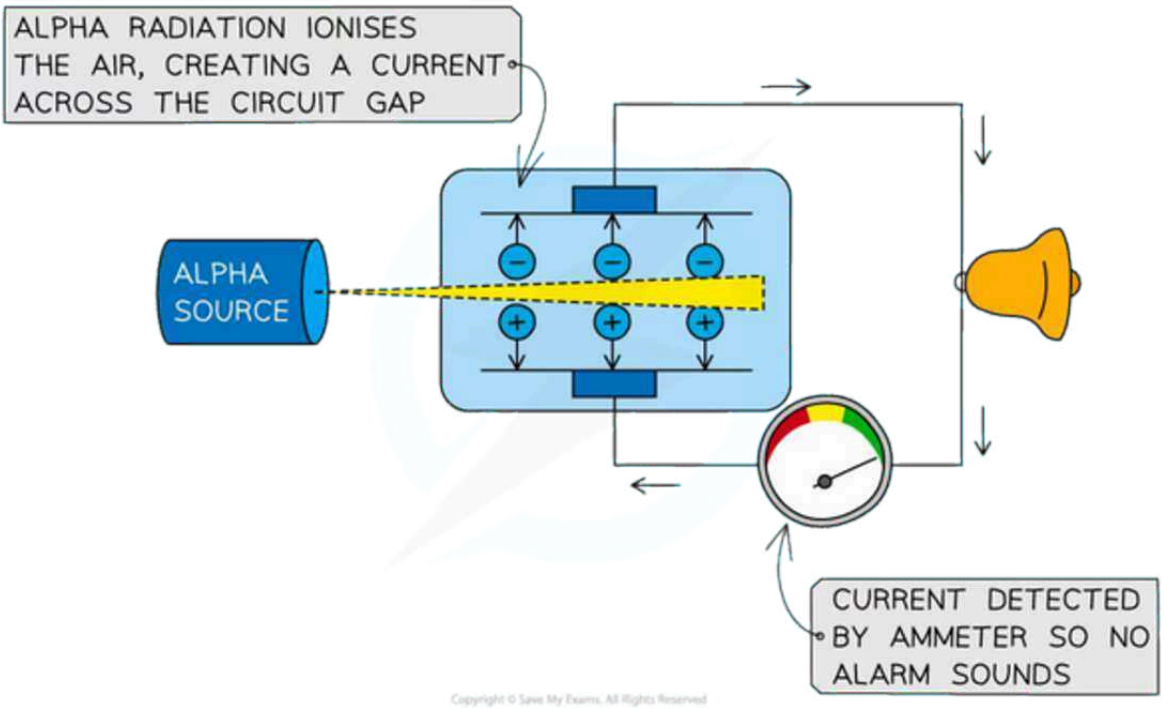
Smoke Detectors

- Alpha particles are used in smoke detectors
- The alpha radiation will normally **ionise** the air within the detector, creating a current
- The alpha emitter is blocked when smoke enters the detector
- The alarm is triggered by a microchip when the sensor no longer detects alpha

Smoke Detector in Normal Operation

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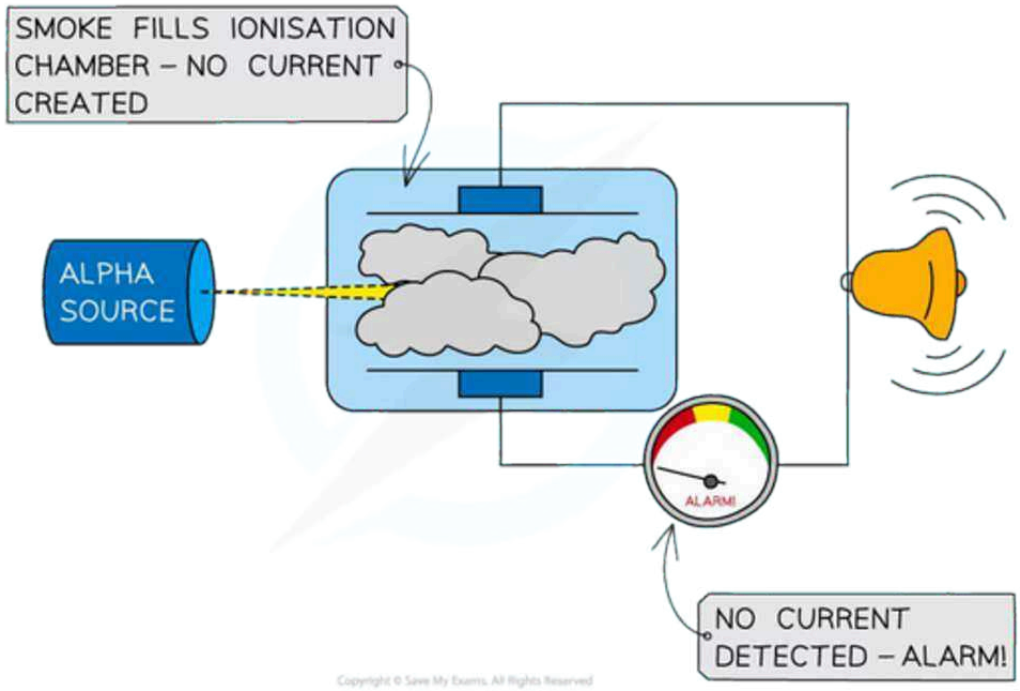
Your notes



How is smoke detected in a smoke alarm?

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Your notes



When alpha particles are stopped by the smoke, this prevents the flow of current and triggers the alarm

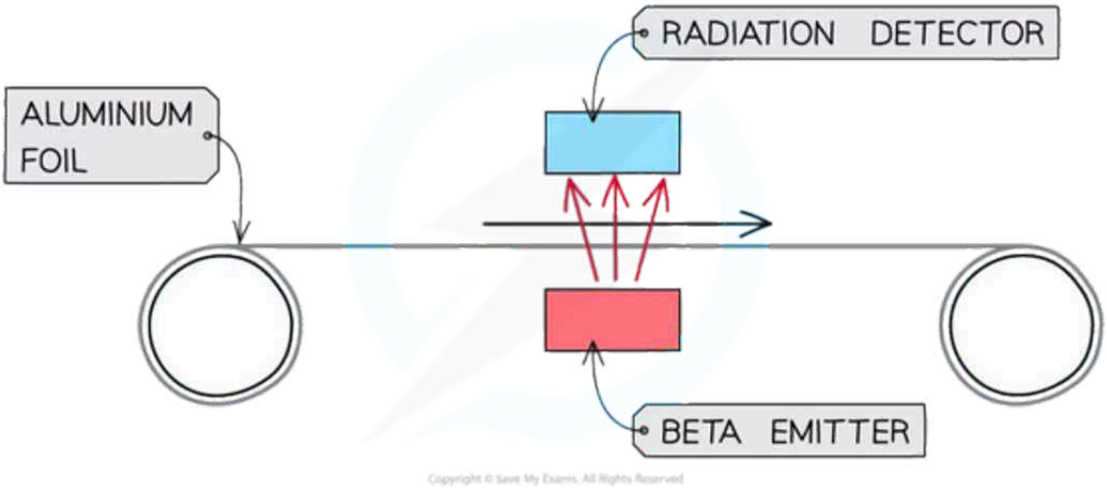
Measuring the Thickness of Materials

- Radiation can be used for tracing and gauging thickness
 - **Beta** particles are most commonly used for this
- As the material moves along a belt above a **beta** source, the particles that are able to penetrate it can be monitored using a detector on the other side
- If the material gets **thicker, more** particles will be absorbed by the material, meaning **less** will arrive at the detector
 - If the material gets **thinner**, more particles will arrive at the detector
- This allows the machine to make **adjustments** to keep the thickness of the material **constant**

Measuring the Thickness of Aluminium using Beta Radiation

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Your notes



Beta particles can be used to measure the thickness of thin materials such as paper, cardboard or aluminium foil

- Beta radiation is used because it will be **partially absorbed** by the material
 - If **alpha** particles were used **all of them would be absorbed** and none would get through
 - If **gamma** were used almost **all of it would get through** and the detector would not be able to sense any difference if the thickness were to change

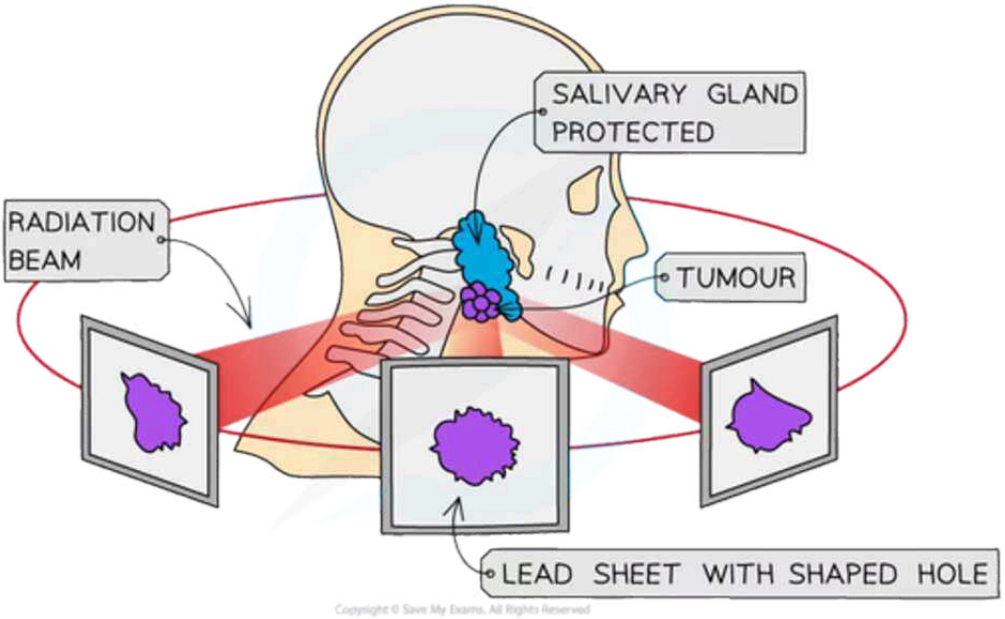
Diagnosis and Treatment of Cancer

- **Radiotherapy** is the name given to the treatment of cancer using radiation
 - Whereas, chemotherapy is the treatment of cancer using chemicals
- Although radiation can cause cancer, it is also highly effective at **treating** it
- Radiation can kill living cells
 - Some cells, such as bacteria and cancer cells, are more susceptible to radiation than others
- Beams of gamma rays are directed at the cancerous tumour
 - Gamma rays are used because they are **able to penetrate the body**, reaching the tumour
 - The beams are moved around to minimise harm to healthy tissue whilst still being aimed at the tumour
- A **tracer** is a radioactive isotope that can be used to track the movement of substances, like blood, around the body
 - A PET scan can detect the emissions from a tracer to diagnose cancer and determine the location of a tumour

Radiation Therapy for Cancer Treatment

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Your notes



Radiation therapy to remove a tumour

Sterilising Food & Medical Equipment

- Gamma radiation is widely used to **sterilise** medical equipment
- Gamma is most suited to this because:
 - It is the most **penetrating** out of all the types of radiation
 - It is penetrating enough to irradiate **all sides** of the instruments
 - Instruments can be sterilised without removing the **packaging**
- Food can be irradiated in order to **kill any microorganisms** that are present in it
- This makes the food last longer and reduces the risk of food-borne infections

The Radura Symbol

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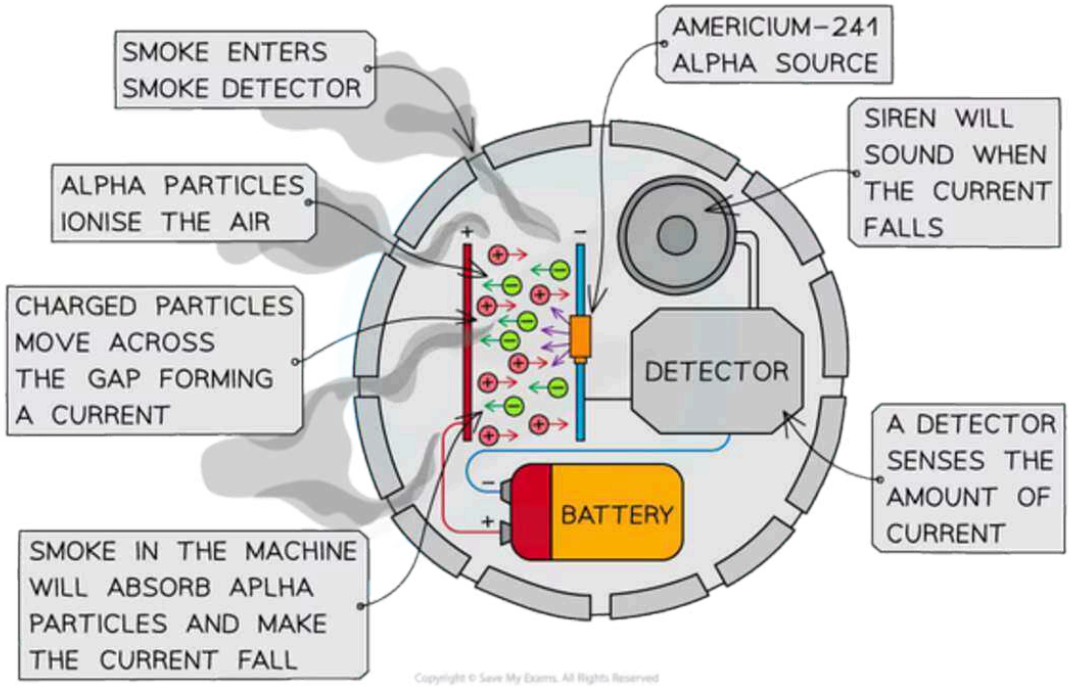
Food that has been irradiated carries this symbol, called the Radura. Different countries allow different foods to be irradiated

Your notes

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Worked example

Use the diagram to explain why is alpha radiation used in smoke detectors, and not beta or gamma radiation.



Answer:

Consider the different properties of alpha, beta and gamma:

- **Alpha** is the most **weakly** penetrating and **strongest** ioniser
- **Beta** and **gamma** have **stronger** penetrating power and **weaker** ionising power

Explain why alpha is the most appropriate choice:

- If beta or gamma radiation were used in a smoke detector, they would pass straight through the smoke and the alarm would not go off
- Therefore, since alpha is **absorbed** by smoke, and beta and gamma are not, this makes it **most suitable** for use in a smoke detector

Your notes

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Exam Tip

If you are presented with an unfamiliar situation in your exam don't panic! Just apply your understanding of the properties of alpha, beta and gamma radiation. Mainly think about the range (how far it can travel) and ionising power of the radiation to help understand which radiation is used in which situation.



Your notes

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Dangers of Radiation

Your notes

Dangers of Radioactivity

- Ionising radiation can damage human cells and tissues at high doses:
- This could be in terms of:
 1. Cell death
 2. Tissue damage
 3. Mutations
 4. Cancer
- As a result, its use needs to be kept to a minimum
- However, the benefits of using radiation in medicine can out way the potential risks
 - The risks posed by the radiation are smaller than the risks associated with leaving the condition untreated
- For example, if a person has a cancerous tumour that is likely to kill them, then it is **less** of a risk to use radiotherapy than to leave the tumour

Tissue Damage

- Radiation is effectively used to destroy cancerous tumour cells
- However, it can cause damage to healthy tissue if it is not properly targeted
- This is mostly from high-energy radiation such as gamma rays and X-rays

Mutations

- If the atoms that make up a DNA strand are ionised then the DNA strand can be damaged
- If the DNA is damaged then the cell may die, or the DNA may be **mutated** when it reforms
- If a mutated cell is able to replicate itself then a **tumour** may form
 - This is an example of **cancer**, which is a significant danger of radiation exposure

Mutation of a Cell by Ionising Radiation

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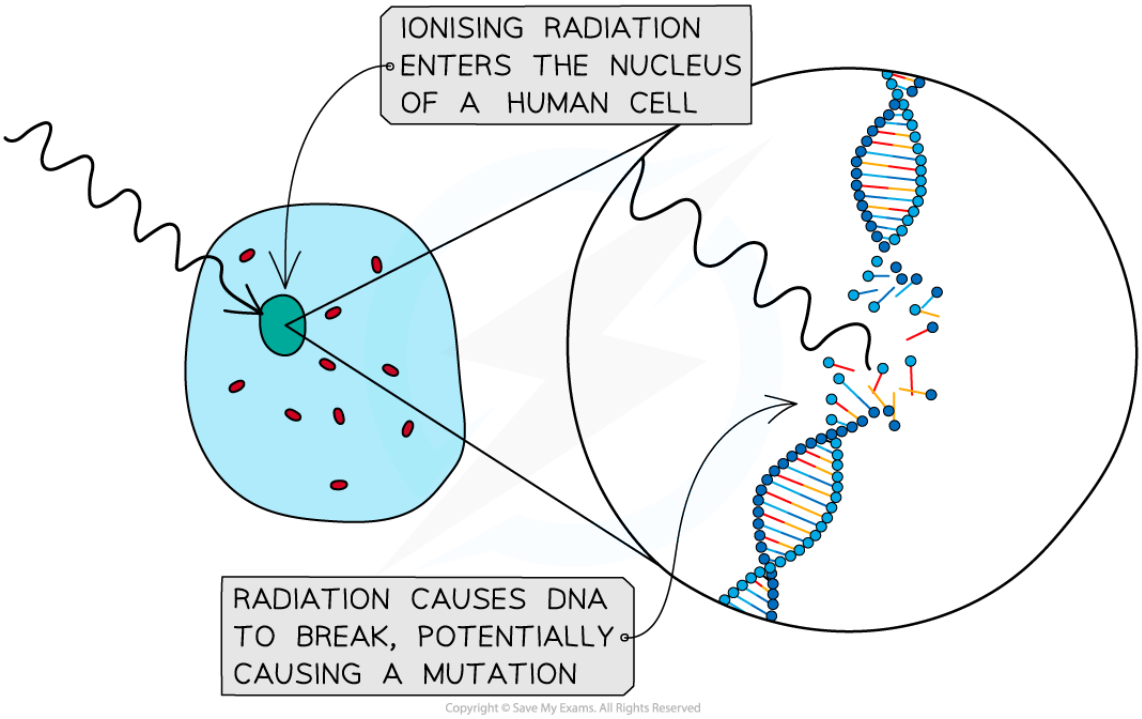


Diagram showing the damage caused to DNA by ionising radiation. Sometimes the cell is able to successfully repair the DNA, but incorrect repairs can cause a mutation

- Acute radiation exposure can have other serious symptoms:
 - It can cause skin **burns**, similar to severe sunburn
 - Radiation can **reduce** the amount of **white blood cells** in the body, making a person more susceptible to infections by lowering their immune system
- Because of this, it is very important to handle radioactive sources carefully

Your notes

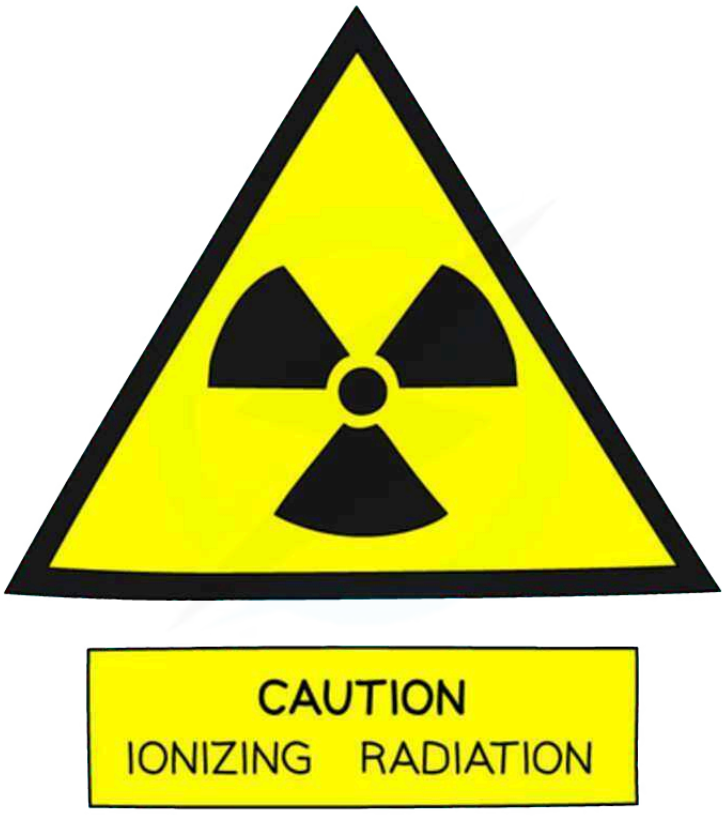
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Safe Storage

Your notes

- The risks associated with handling radioactive sources can be minimised by following a few simple procedures:
 - Sources must be stored in **lead-lined boxes** and kept at a distance from people
 - Sources must be handled for the **minimum time possible** and then returned to their boxes immediately
 - During use, sources should be handled with a **pair of tongs** at arm's length
- When using tongs, gloves and safety specs are usually unnecessary when handling radioactive materials, unless there is a risk of the material leaking onto other items

Hazard Symbol for Radioactivity



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Whenever you see this symbol, it means a source of ionising radiation is nearby and you should proceed with caution

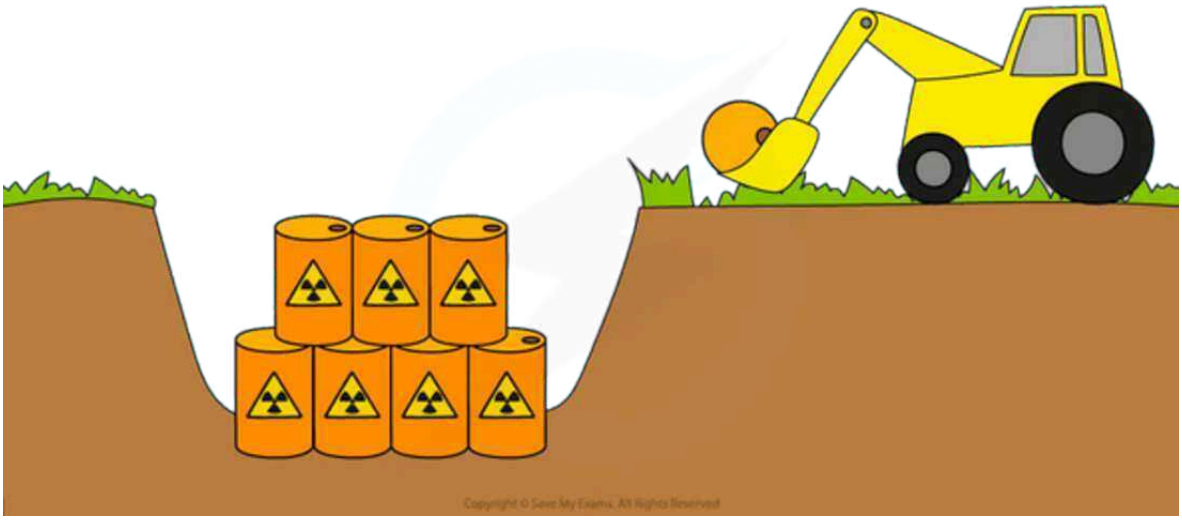
Disposing of Radioactive Waste

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- If an isotope has a long half-life then a sample of it will decay slowly
 - Although it may not emit a lot of radiation, it will **remain radioactive for a very long time**
- Sources with long half-life values present a risk of contamination for a much longer time
- Radioactive waste with a long half-life is buried underground to prevent it from being released into the environment

Your notes

Disposal of Radioactive Waste



Radioactive waste with a long half-life must be buried deep underground

Worked example

A student plans to use a gamma source to conduct an experiment.

List **four** precautions that the student should take in order to minimise the risk to themselves when using the source.

Answer:

The student should...

1. Keep the source in a lead-lined container at all times when not in use
2. Use tongs to move the source, rather than handling it directly
3. Ensure an adequate distance is kept between them and the source during the experiment
4. Keep a record of the date and time that the radiation has been used

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Cambridge O Level Physics

Your notes

6.1 Earth & The Solar System

Contents

- The Earth, Moon & Sun
- Calculating Orbital Speeds
- The Solar System
- Orbiting Bodies
- Gravitational Effects on Orbits

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The Earth, Moon & Sun

Your notes

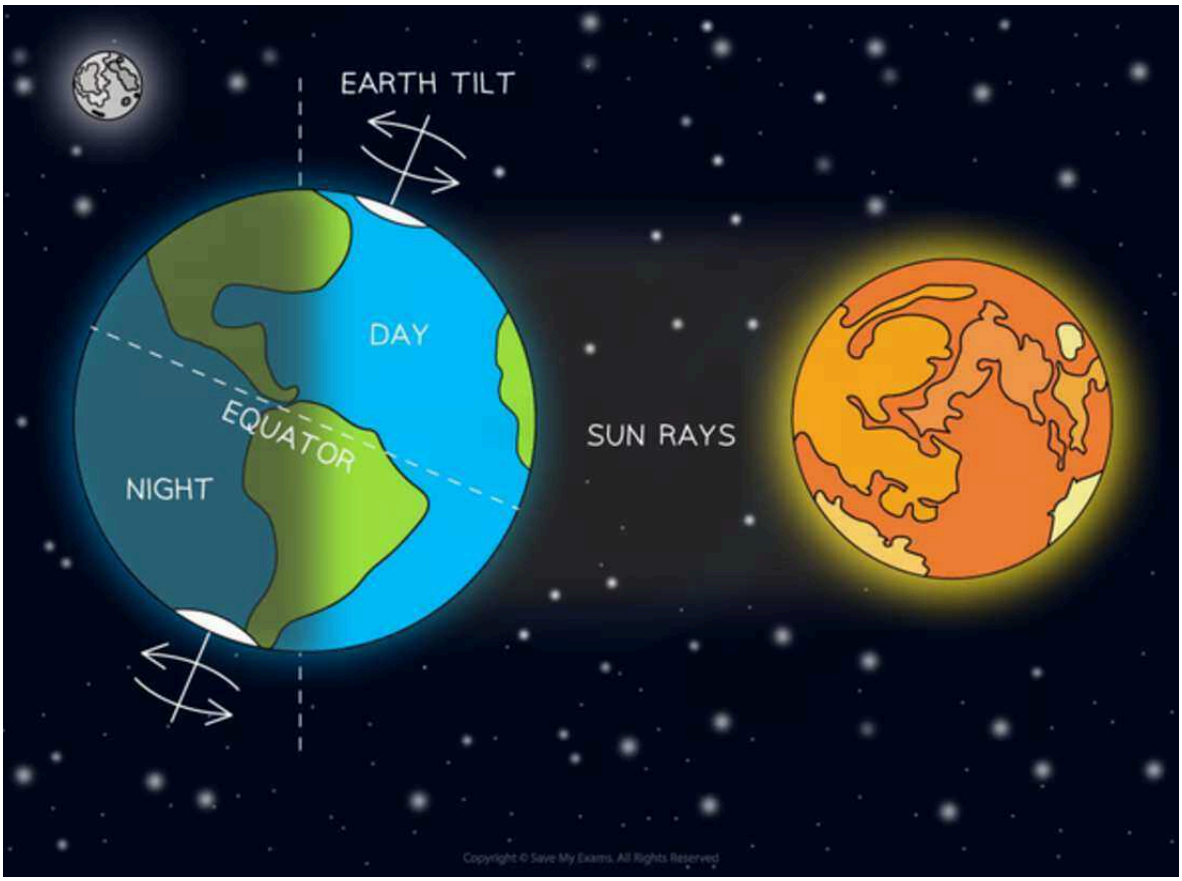
The Earth, Moon & Sun

- The Earth is a rocky **planet** that
 - Orbits the Sun once every 365 days (1 year)
 - Follows an approximately circular (**elliptical**) orbit
 - Completes one full rotation on its axis once every 24 hours (1 day)
 - Is tilted on its axis (a line through the north and south poles) at an angle of approximately 23.5°

The Earth's Axis

- The Earth's rotation on its tilted axis creates **day** and **night**
 - Day is experienced by the half of the Earth's surface that is facing the Sun
 - Night is the other half of the Earth's surface, facing away from the Sun

Day & Night on Earth



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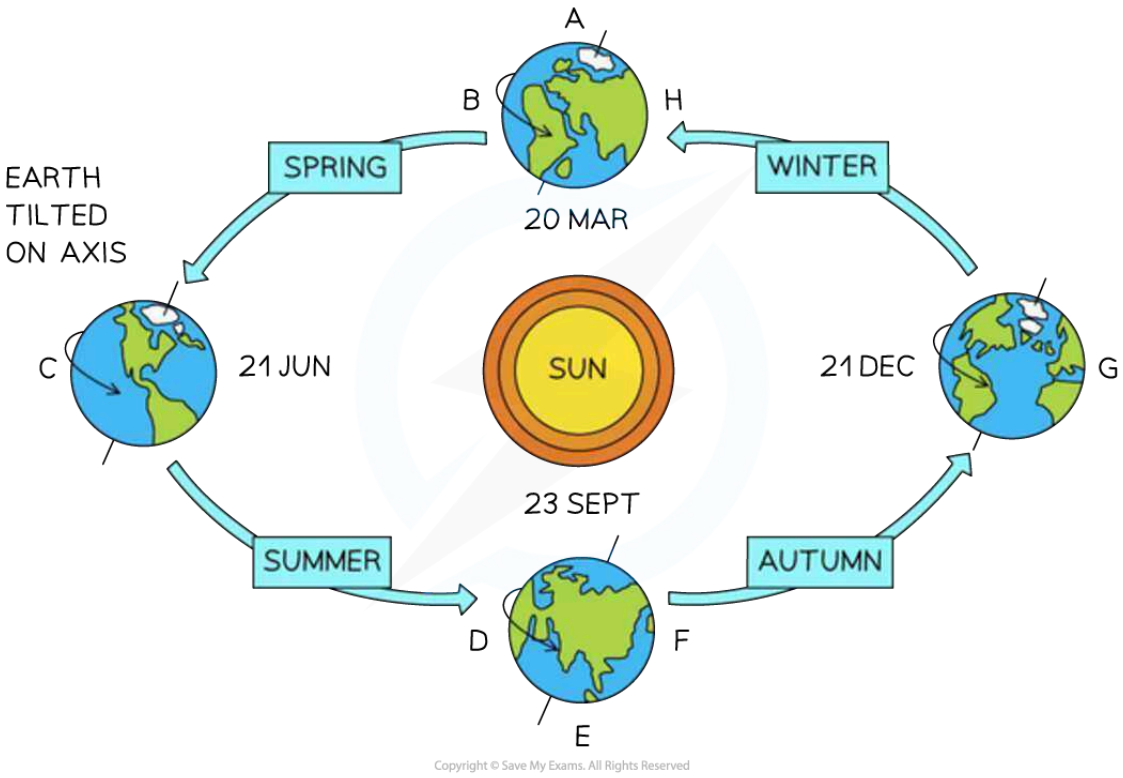
Day and night are caused by the Earth's rotation

Your notes

The Earth's Orbit

- The Earth orbits the Sun once every year, which is approximately **365 days**
- The combination of the orbiting of the Earth around the Sun and the Earth's tilt creates the **seasons**

Seasons on Earth



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Use this image

Seasons in the Northern Hemisphere are caused by the tilt of the Earth

- Over parts B, C and D of the orbit, the northern hemisphere is tilted **towards** the Sun
 - This means daylight hours are more than hours of darkness
 - This is **spring and summer**
- The southern hemisphere is tilted **away** from the Sun
 - This means there are shorter days than night
 - This is **autumn and winter**

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- Over parts F, G and H of the orbit, the northern hemisphere is tilted **away** from the Sun
 - The situations in both the northern and southern hemispheres are reversed
 - It is autumn and winter in the northern hemisphere, but **at the same time** it is spring and summer in the southern hemisphere
- At C:
 - This is the **summer solstice**
 - The northern hemisphere has the longest day, whilst the southern hemisphere has its shortest day
- At G:
 - This is the **winter solstice**
 - The northern hemisphere has its shortest day, whilst the southern hemisphere has its longest day
- At A and D:
 - Night and day are equal in **both** hemispheres
 - These are the **equinoxes**

Your notes

The Moon

- The Moon is a **satellite** that orbits around the Earth
- It travels around the Earth in roughly a circular orbit once a month, which takes around **28 days**
- The Moon revolves around its own axis in a month so always has the **same** side facing the Earth
 - We never see the hemisphere that is always facing away from Earth, although astronauts have orbited the Moon and satellites have photographed it
- The Moon shines with reflected light from the Sun, **it does not produce its own light**

The Moon



We always see the same side of the Moon as it rotates on its axis and orbits the Earth at the same rate

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Calculating Orbital Speeds


Your notes

Orbital Speed

- When planets move around the Sun, or a moon moves around a planet, they orbit in **circular motion**
 - This means that in one orbit, a planet travels a distance equal to the circumference of a circle (the shape of the orbit)
 - This is equal to $2\pi r$ where r is the radius of a circle
- The relationship between speed, distance and time is:

$$speed = \frac{distance}{time}$$

- the average orbital speed of an object can be defined by the equation:

$$v = \frac{2\pi r}{T}$$

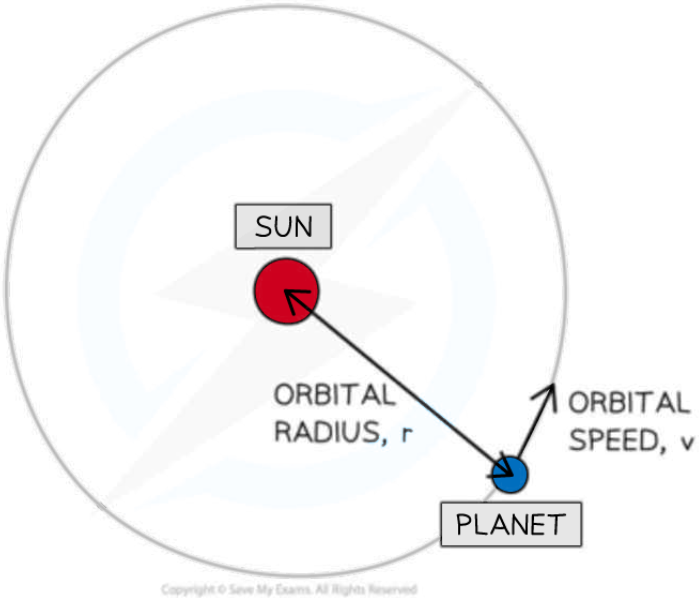
- Where:
 - v = orbital speed in metres per second (m/s)
 - r = average radius of the orbit in metres (m)
 - T = orbital period in seconds (s)
- This orbital period (or time period) is defined as:

 The time taken for an object to complete one orbit
- The orbital radius r is always taken from the **centre** of the object being orbited to the object orbiting

Orbital Motion

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Your notes



Orbital radius and orbital speed of a planet moving around a Sun

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Your notes

Worked example

The Hubble Space Telescope (HST) moves in a circular orbit around the Earth. Its distance above the Earth's surface is 560 km and the radius of the Earth is 6400 km. The HST completes one orbit in 96 minutes.



Calculate the orbital speed of the HST in m/s.

Answer:

Step 1: List the known quantities

- Radius of the Earth, R = 6400 km
- Distance of the telescope above the Earth's surface, h = 560 km
- Time period, T = 96 minutes

Step 2: Write the relevant equation

$$v = \frac{2\pi r}{T}$$

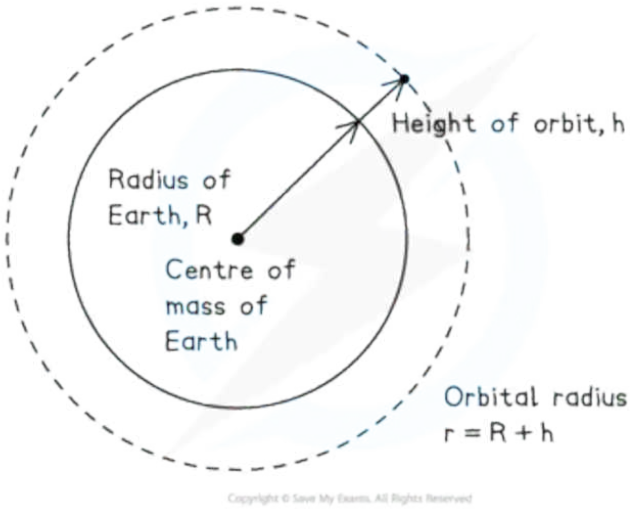
Step 3: Calculate the orbital radius, *r*

- The **orbital radius** is the distance from the **centre** of the Earth to the telescope

$$r = R + h$$

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Your notes



$$r = 6400 + 560 = 6960 \text{ km}$$

Step 4: Convert any units

- The time period needs to be in seconds

$$1 \text{ minute} = 60 \text{ seconds}$$

$$96 \text{ minutes} = 60 \times 96 = 5760 \text{ s}$$

- The radius needs to be in metres

$$1 \text{ km} = 1000 \text{ m}$$

$$6960 \text{ km} = 6\,960\,000 \text{ m}$$

Step 5: Substitute values into the orbital speed equation

$$v = \frac{2\pi \times 6\,960\,000}{5760} = 7592.18 = 7590 \text{ m/s}$$

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Exam Tip

Remember to check that the orbital radius *r* given is the distance from the **centre** of the Sun (if a planet is orbiting a Sun) or the planet (if a moon is orbiting a planet) and not just from the surface. If the distance is a height above the surface you must add the radius of the body, to get the height above the centre of mass of the body.

This is because orbits are caused by the mass, which can be assumed to act at the centre, rather than the surface.

Don't forget to check your units and convert any if required!



Your notes

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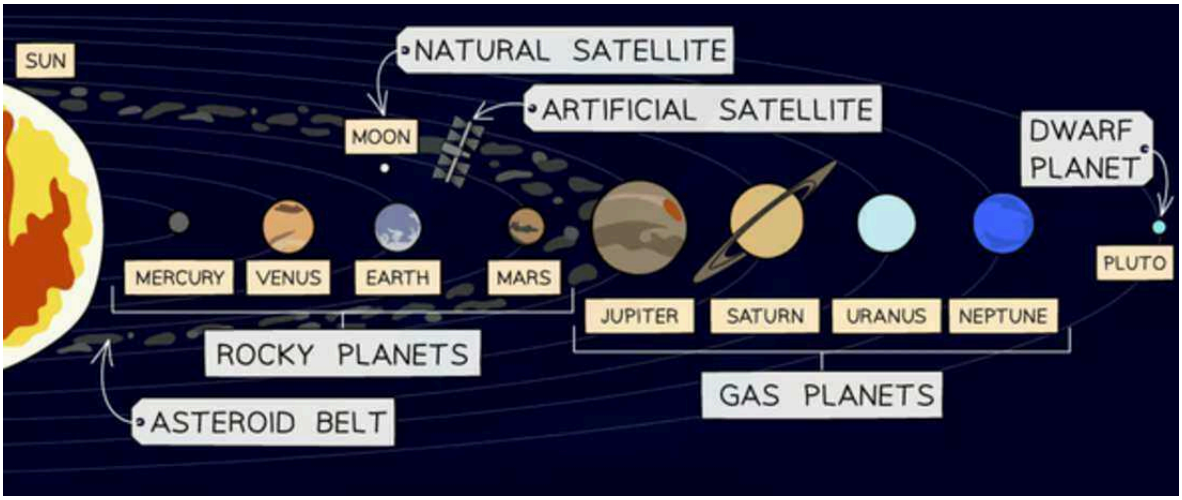
The Solar System

Your notes

The Solar System

- The Solar System consists of:
 1. The Sun
 2. Eight planets
 3. Natural and artificial satellites
 4. Dwarf planets
 5. Asteroids and comets

Objects in the Solar System



The Solar System contains a star (the Sun), 8 planets, minor planets, moons and other smaller bodies

The Sun & the Planets

- The **Sun** lies at the centre of the Solar System
 - The Sun is a **star** that makes up over 99% of the mass of the solar system
- There are **eight planets** and an unknown number of **dwarf planets** which orbit the Sun
 - The **gravitational field** around planets is strong enough to have pulled in all nearby objects with the exception of natural satellites
 - The gravitational field around a **dwarf planet** is **not strong enough** to have pulled in nearby objects
- The 8 planets in our Solar System in ascending order of the distance from the Sun are:
 - Mercury
 - Venus

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- Earth
- Mars
- Jupiter
- Saturn
- Uranus
- Neptune


Your notes

Satellites

- There are two types of satellite:
 - Natural
 - Artificial
- Some planets have **moons** which orbit them
 - Moons are an example of **natural satellites**
- **Artificial satellites** are man-made and can orbit any object in space
 - The International Space Station (ISS) orbits the Earth and is an example of an artificial satellite

Asteroids & Comets

- **Asteroids** and **comets** also orbit the sun
- An **asteroid** is a small **rocky object** which orbits the **Sun**
 - The **asteroid belt** lies between **Mars and Jupiter**
- **Comets** are made of **dust and ice** and orbit the **Sun** in a different orbit to those of planets
 - The ice melts when the comet approaches the Sun and forms the comet's **tail**

Exam Tip

You need to know the order of the 8 planets in the solar system. The following mnemonic gives the first letter of each of the planets to help you recall them:

My **V**ery **E**xcellent **M**other **J**ust **S**erved **U**s **N**oodles

Mercury, **V**enus, **E**arth, **M**ars, **J**upiter, **S**aturn, **U**ranus, **N**eptune

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Light Speed


Your notes

- The planets and moons of the Solar System are visible from Earth when they **reflect light** from the Sun
 - The outer regions of the Solar System are around 5×10^{12} m from the Sun, which means even light takes some time to travel these distances
- The light we receive on Earth from the Sun takes **8 minutes** to reach us
 - The nearest star to us after the Sun is so far away that light from it takes **4 years** to reach us
 - The Milky Way galaxy contains billions of stars, huge distances away, with the light taking even longer to be seen from Earth
- The speed of light, equal to 3×10^8 m/s, is constant everywhere in the Universe
- The time taken to travel a certain distance in the Solar System can be calculated by using the equation:

$$speed = \frac{distance}{time}$$

- And rearranging it for time:

$$time = \frac{distance}{speed}$$

Worked example

The radius of Mercury's orbit around the Sun is 5.8×10^9 m.

Calculate the time taken for light from the Sun to reach Mercury.

Answer:

Step 1: State the equation for the time taken for light to travel a certain distance

$$time = \frac{distance}{speed}$$

Step 2: Substitute the values into the equation

- The distance travelled is the radius of the orbit = 5.8×10^9 m
- Speed = the speed of light = 3.0×10^8 m/s

$$time = \frac{5.8 \times 10^9}{3.0 \times 10^8} = 19.33333$$

Step 3: Round up the answer and include units

$$\text{time} = 19.3 \text{ s}$$

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Exam Tip

The speed of light is **very** fast. This is why in our everyday life things like switching on a light seem to be instant. However, this is only because the light travels very fast and the distances are very small. In large, astronomical distances which can be millions or even billions of kilometres, the limit of the speed of light starts to have an effect.

For example, it takes light 8 minutes to travel from the Sun to the Earth. This means we are seeing the Sun as it was eight minutes ago. If the Sun was to disappear, we would not notice till eight minutes later. Although, by that time, time delay would be the least of our worries...

p.s.: The Sun is not going to vanish!



Your notes

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Orbiting Bodies

Your notes

Analysing Orbits

- Over many years, data about all the planets, moons and the Sun have been collected
- This is not just for general interest, but to indicate:
 - Factors that affect conditions on the surface of the planets
 - Environmental problems that a visit (using manned spaceships or robots) would encounter

Data for the planets in the Solar System

planet	orbital distance from Sun / million km	orbital period	density / kg/m^3	surface temperature / °C	surface gravitational field strength / N/kg
Mercury	57.9	88 days	5427	350	3.7
Venus	108.2	225 days	5243	460	8.9
Earth	149.6	365 days	5514	20	9.8
Mars	227.9	687 days	3933	-23	3.7
Jupiter	778.6	11.9 years	1326	-120	23.1
Saturn	1433.5	29.5 years	687	-180	9.0
Uranus	2872.5	75 years	1271	-210	8.7
Neptune	4495.1	165 years	1638	-220	11.0

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Worked example

State and explain the relationship between the distance of a planet from the Sun and its

(a) surface temperature
(b) orbital period
(c) density

Answer:

(a)

The relationship between distance from the Sun and surface temperature is...

- The closer a planet is to the Sun, the **hotter** its surface temperature

This can be seen in the data as...

- The planets closest to the Sun are the **hottest** e.g. Mercury has a surface temperature of 350° (Note: Venus has the hottest surface temperature due to its dense atmosphere which traps heat)
- The planets furthest from the Sun are the **coldest** e.g. Neptune has a surface temperature of −220°C

Explanation:

- The planets nearer to the Sun receive a greater proportion of the emitted **heat radiation** compared to the further planets

(b)

The relationship between distance from the Sun and orbital period is...

- The closer a planet is to the Sun, the **shorter** its orbital period

This can be seen in the data as...

- The planets closest to the Sun have the **shortest** orbital periods e.g. Mercury completes one orbit in 88 days
- The planets furthest from the Sun have the **longest** orbital periods e.g. Neptune completes one orbit in 165 years

Explanation:

- The Sun's gravitational field strength is **strongest** at Mercury and decreases with distance
- Therefore, the planets which are closer to the Sun travel **faster** than the planets which are farther away
- So, the closest planets move faster and have a shorter distance to travel, meaning they complete orbits in a quicker time

Your notes

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(c)

The relationship between distance from the Sun and density is...

- The 4 closest planets to the Sun have the **greatest** densities
- The 4 furthest planets to the Sun have the **lowest** densities

This can be seen in the data as...

- Mercury, Venus, Earth and Mars all have densities around 4000–5000 kg/m^3
- Jupiter, Saturn, Uranus and Neptune all have densities around 1000–2000 kg/m^3

Explanation:

- The four planets nearest to the Sun must have formed in the hotter **inner** regions of the early Solar System where **higher density** material (rocks & metals) collected
- The four planets furthest from the Sun must have formed in the cooler **outer** regions of the early Solar System where **lower density** material (water and gases) collected

Exam Tip

Although you don't need to memorise any of the numbers in the table, you must be able to confidently analyse and interpret it.

Look out for trends such as one variable increasing whilst the other decreases (or also increases).

Think carefully about why that may be with what you have already learnt about the planets from this topic. For example, what is the planet made of? What is its distance from the Sun and how does this affect it?

Your notes

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Gravitational Effects on Orbits

Your notes

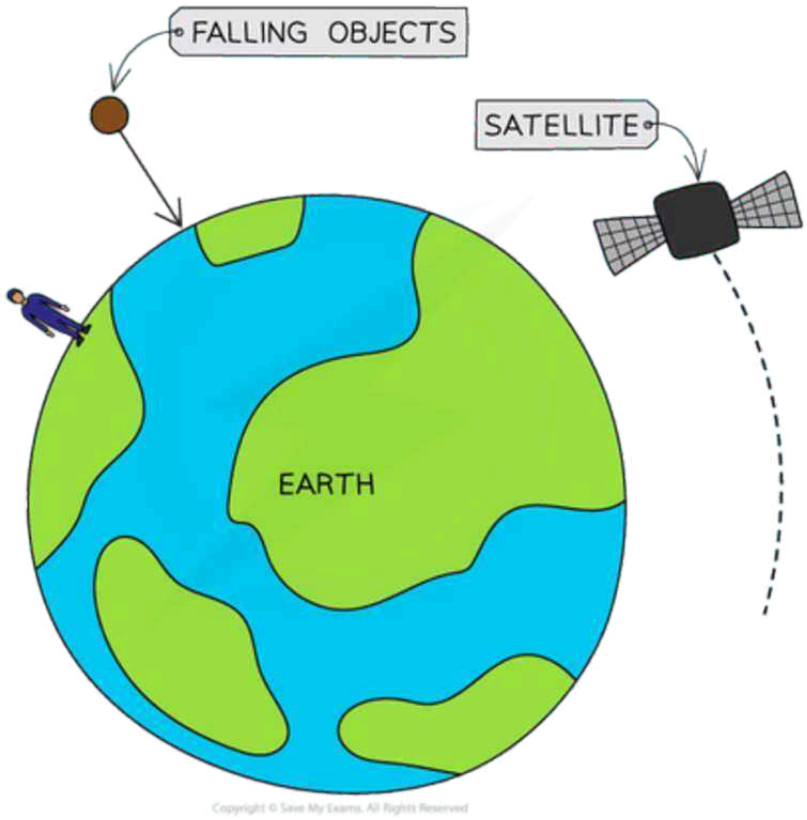
Gravitational Field Strength & Planets

- The strength of gravity on different planets after an object's weight on that planet
- Weight is defined as:

 The force acting on an object due to gravitational attraction

- Planets have strong gravitational fields
 - Hence, they attract nearby masses with a strong gravitational force
- Because of weight:
 - Objects stay firmly on the ground
 - Objects will always fall to the ground
 - Satellites are kept in orbit

The Effect of Gravity on Earth



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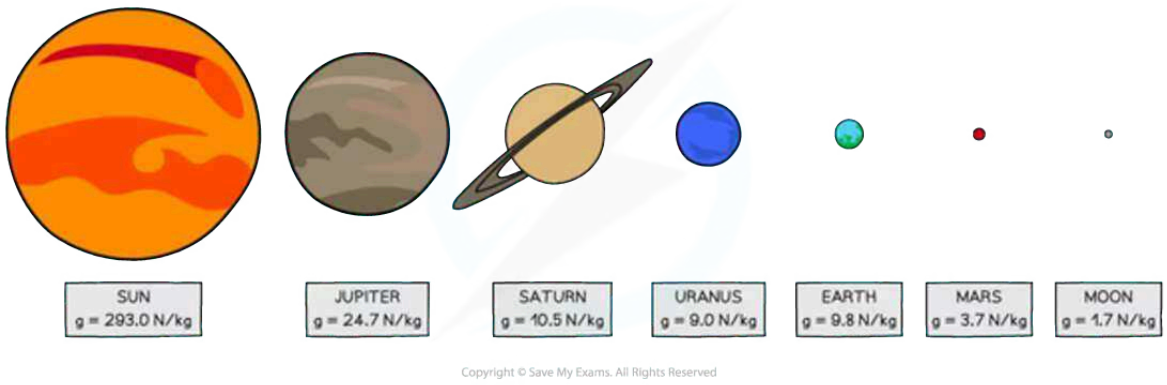
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Your notes

Objects are attracted towards the centre of the Earth due to its gravitational field strength

- Both the weight of any body and the value of the gravitational field strength *g* differs between the surface of the Earth and the surface of other bodies in space, including the Moon because of the planet or moon's **mass**
 - The greater the mass of the planet then the greater its gravitational field strength
 - A higher gravitational field strength means a larger attractive force towards the centre of that planet or moon
- *g* varies with the distance from a planet, but on the surface of the planet, it is roughly the **same**
 - The strength of the field around the planet **decreases** as the distance from the planet **increases**
- However, the value of *g* on the surface varies dramatically for different planets and moons
- The gravitational field strength (*g*) on the **Earth** is approximately 10 N/kg
- The gravitational field strength on the surface of the **Moon** is **less** than on the Earth
 - This means it would be **easier** to lift a mass on the surface of the Moon than on the Earth
- The gravitational field strength on the surface of the gas giants (eg. Jupiter and Saturn) is **more** than on the Earth
 - This means it would be **harder** to lift a mass on the gas giants than on the Earth

Values of Gravitational Field Strength



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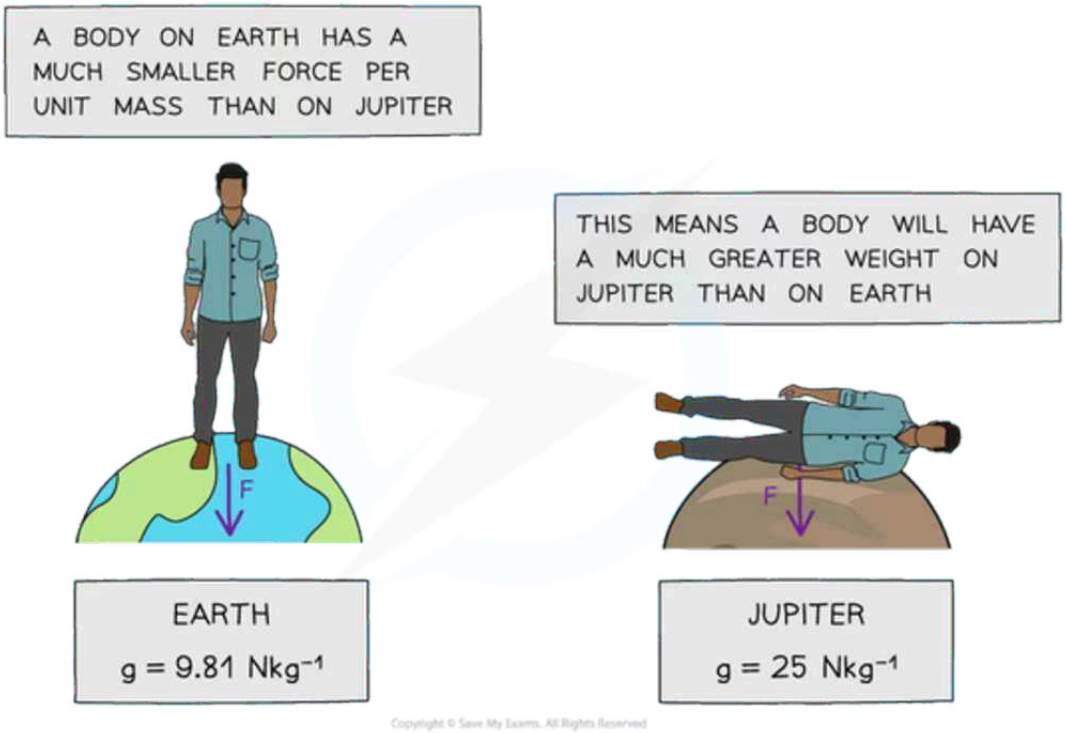
Value for g on the different objects in the Solar System

- On such planets such as Jupiter, an object's mass remains the same at all points in space
- However, their weight will be a lot greater meaning for example, a human will be unable to fully stand up

Comparison of *g* on Earth & Jupiter

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Your notes



A person's weight on Jupiter would be so large a human would be unable to fully stand up

Exam Tip

You do not need to remember the value of *g* on different planets for your exam, the value of *g* for Earth will be given in the exam question.

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Gravitational Attraction of the Sun

Your notes

- There are many orbiting bodies in the Solar System which can be defined by the object that they orbit around

Orbiting Bodies in the Solar System

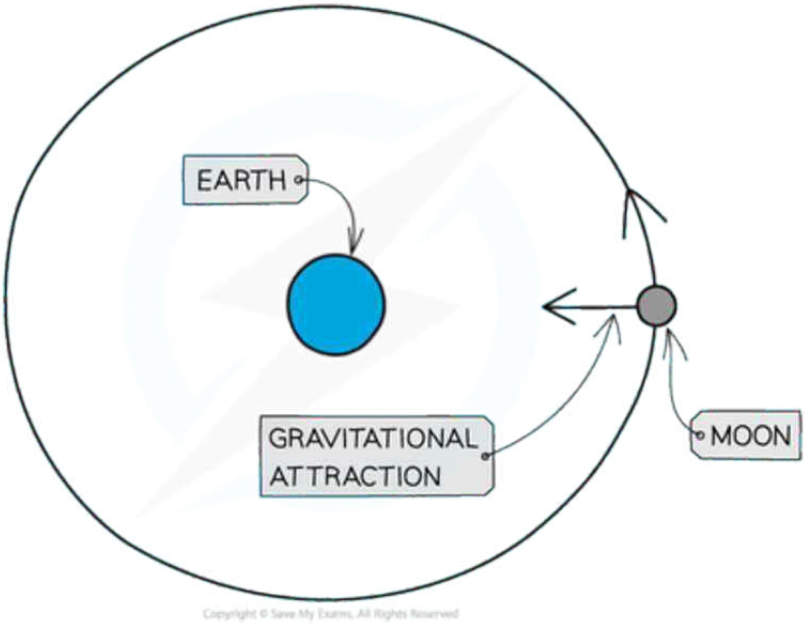
Orbiting body	What it orbits
planet	the Sun
the Moon	planet
comet	the Sun
asteroid	the Sun
artificial satellite	any body in the Solar System (apart from the Sun)

- A **smaller** body or object will **orbit** a **larger** body
 - For example, a planet orbiting the Sun
- In order to orbit a body such as a star or a planet, there has to be a **force** pulling the object **towards** that body
 - **Gravity** provides this force
- Therefore, it is said that the force that keeps a planet in orbit around the Sun is the **gravitational attraction** of the Sun
- The gravitational force exerted by the larger body on the orbiting object is **always attractive**
 - Therefore, the gravitational force always acts **towards the centre** of the larger body
- Therefore, the force that keeps an object in orbit around the Sun is the **gravitational attraction** of the Sun and is always directed from the orbiting object to the centre of the Sun
- The gravitational force will cause the body to move and maintain in a **circular path**

Orbital Motion of the Moon

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Your notes

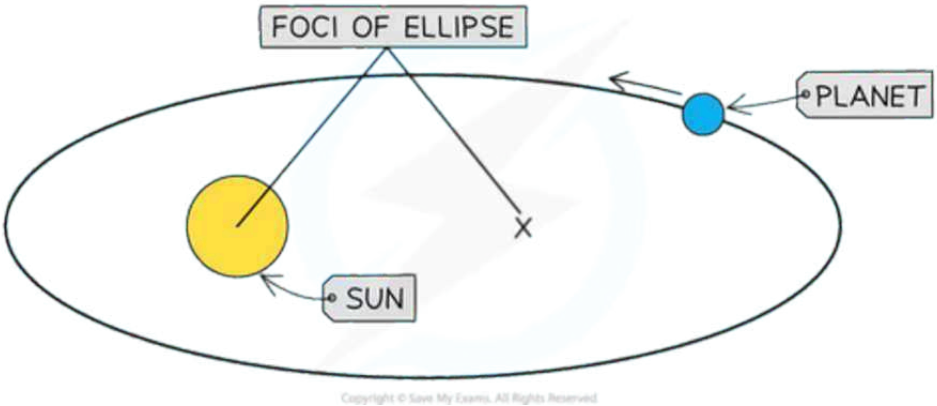


Gravitational attraction causes the Moon to orbit around the Earth

Non-Circular Orbits

- Orbits of planets, minor planets and comets are **elliptical**
 - An ellipse is just a 'squashed' circle
- Planets, minor planets and comets have elliptical orbits
 - However, the Sun is not at the centre of an elliptical orbit
 - This is only the case when the orbit is approximately circular

An elliptical orbit



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Planets and comets travel in elliptical orbits, but the Sun is not at the centre of these orbits

Exam Tip

You will not be asked to do any calculations with elliptical orbits. If you are asked to calculate the time period, orbital speed or radius of an orbit, it can be assumed that it is circular.



Your notes

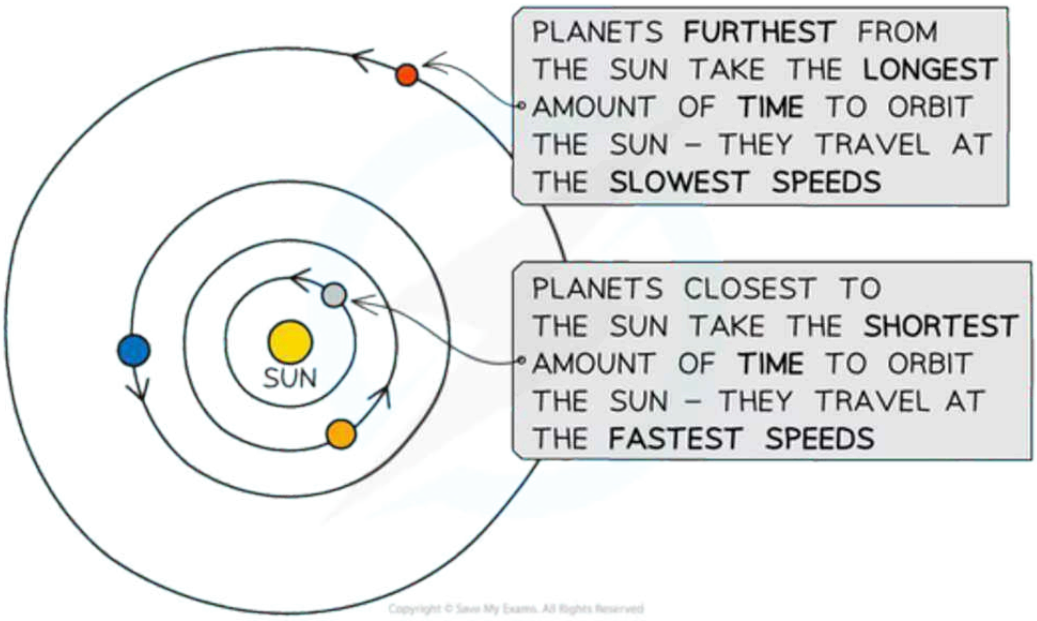
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Sun's Gravitational Field & Distance

Your notes

- As the distance from the Sun increases:
 - The strength of the Sun's gravitational field on the planet decreases
 - The orbital speed of the planet decreases
- To keep an object in a circular path, it must have a centripetal force
 - For planets orbiting the Sun, this force is **gravity**
- Therefore, the strength of the Sun's gravitational field in the planet affects how much centripetal force is on the planet
 - This strength **decreases** the further away the planet is from the Sun, and the weaker the centripetal force
- The centripetal force is **proportional** to the orbital speed
 - Therefore, the planets further away from the Sun have a smaller orbital speed
 - This also equates to a longer orbital duration

Orbital Speed & Distance



How the speed of a planet is affected by its distance from the Sun

- This can be seen from data collected for a planet's orbital distance against their orbital speed
 - For example, Neptune travels much slower than Mercury

Orbital distance, period & speed of the planets in the Solar System

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Planet	Orbital distance from Sun / million km	Orbital period	Orbital speed / km/s
Mercury	57.9	88 days	47.9
Venus	108.2	225 days	35.0
Earth	149.6	365 days	29.8
Mars	227.9	687 days	24.1
Jupiter	778.6	11.9 years	13.1
Saturn	1433.5	29.5 years	9.7
Uranus	2872.5	75 years	6.8
Neptune	4495.1	165 years	5.4


Your notes

Exam Tip

Be careful with your wording in this topic when talking about gravity. It is important to refer to the **force** of gravity as 'gravitational attraction', ' strength of the Sun's gravitational field' or 'the force **due to** gravity'. Avoid terms such as 'the Sun's gravity' or even more vague, 'the force from the Sun'.

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Cambridge O Level Physics

Your notes

6.2 Stars & The Universe

Contents

- The Sun as a Star
- Stars
- The Universe

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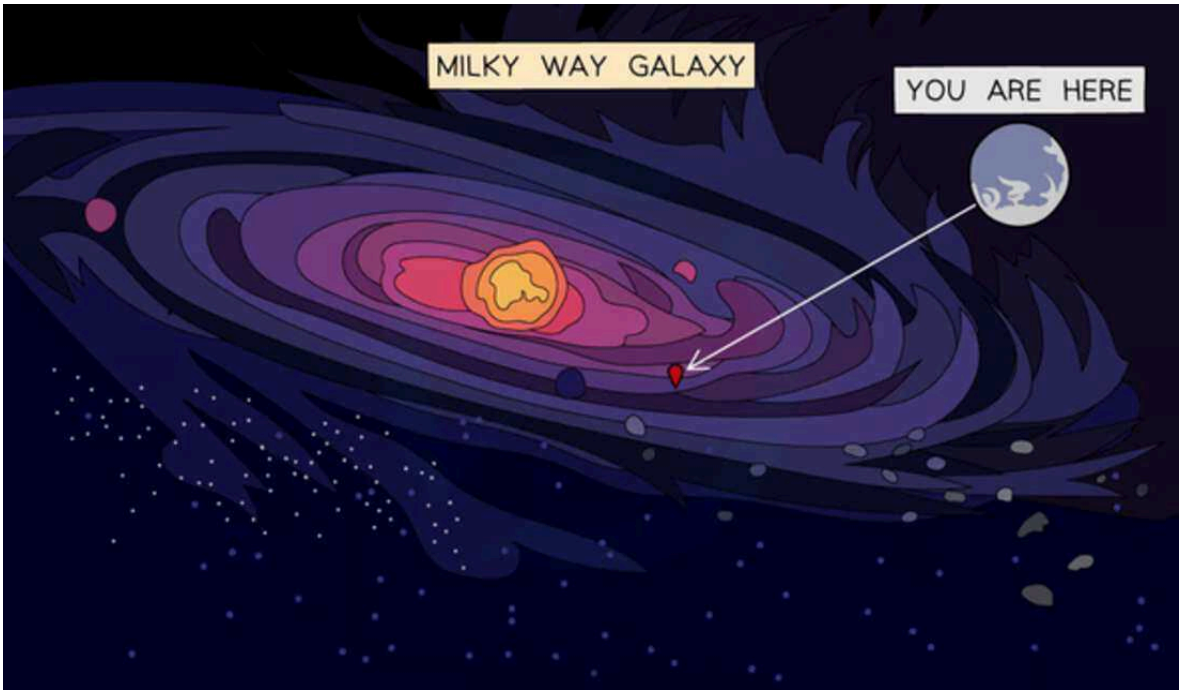
The Sun as a Star

Your notes

The Milky Way

- **Galaxies** are made up of **billions of stars**
- The **Universe** is made up of many different galaxies
- The Sun is one of the billions of stars in a galaxy called the **Milky Way**
- Other stars in the Milky Way galaxy are **much further away** from Earth than the Sun is
- Some of these stars also have **planets** which orbit them

Our Place in Space



Our solar system is just one out of potentially billions in our galactic neighbourhood, the Milky Way. There are estimated to be more than 100 billion galaxies in the entire universe

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The Sun

Your notes

- The **Sun** lies at the centre of the Solar System
 - The Sun is a **star** which makes up over 99% of the mass of the solar system
 - The fact that most of the mass of the Solar System is concentrated in the Sun is the reason the smaller **planets orbit the Sun**
- The planets are kept in orbit due to the gravitational pull of the Sun
- The Sun is a **medium-sized star** consisting of mainly **hydrogen** and **helium**
- It radiates most of its energy in the **infrared**, **visible** and **ultraviolet** regions of the electromagnetic spectrum

The Sun

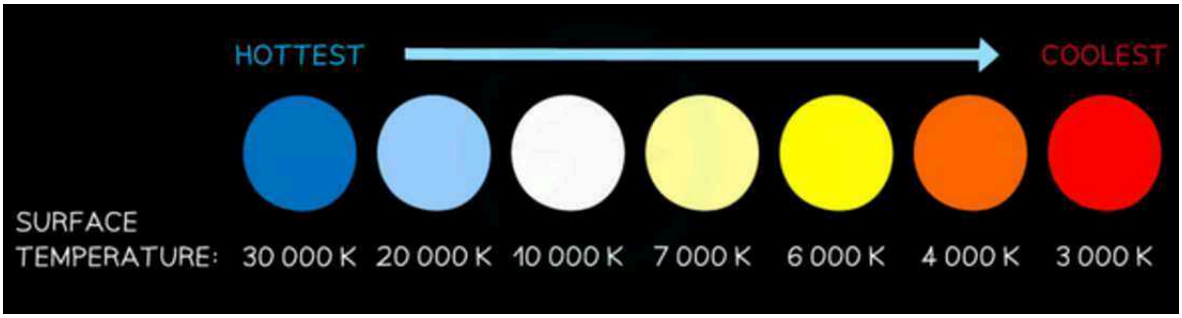


Our Sun (Image courtesy of NASA)

- Stars come in a wide range of sizes and colours, from yellow stars to red dwarfs, from blue giants to red supergiants
 - These can be classified according to their **colour**
- Warm objects emit infrared and extremely hot objects emit visible light as well
 - Therefore, the **colour** they emit depends on how **hot** they are
- A star's colour is related to its **surface temperature**
 - A **red** star is the **coolest** (at around 3000 K)
 - A **blue** star is the **hottest** (at around 30 000 K)

Temperature & Colour of Stars

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The colour of a star correlates to its temperature

Your notes

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Nuclear Fusion in Stars

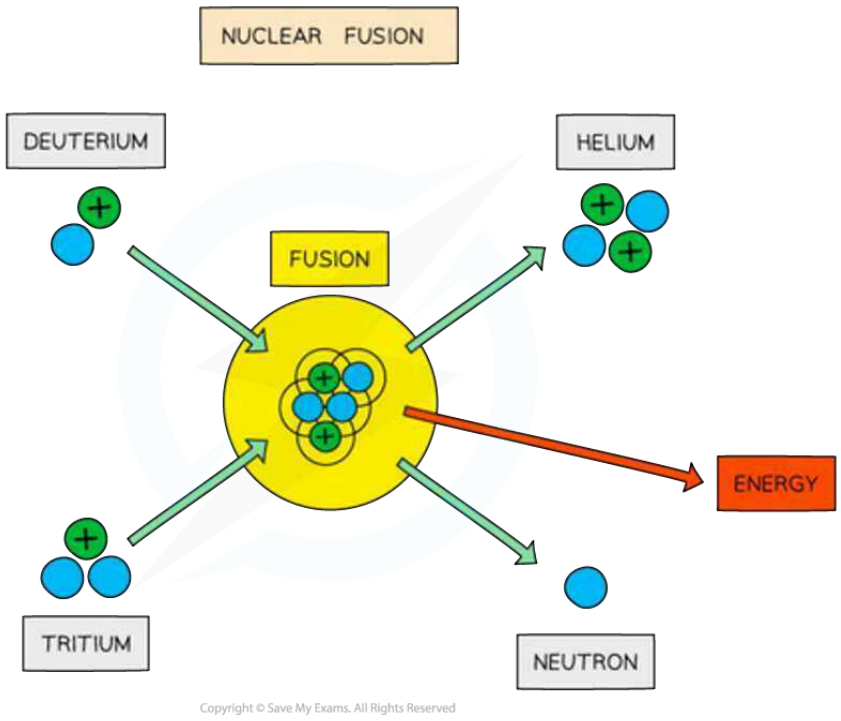
Your notes

- In the centre of a stable star, hydrogen atoms undergo **nuclear fusion** to form helium
- The equation for the reaction is shown here:

$$^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$$

- The equation shows $^{2}_{1}\mathrm{H}$ (deuterium) and $^{3}_{1}\mathrm{H}$ (tritium) which are both isotopes of hydrogen
 - They can be formed through other fusion reactions in the star
- A **huge** amount of energy is released in the reaction
- This provides a pressure that prevents the star from collapsing under its gravity

Nuclear Fusion in Stars



The fusion of deuterium and tritium to form helium with the release of energy

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Worked example

An example of a hydrogen fusion reaction which takes place in stars is shown here.

$$_{1}^{2}\mathrm{H} + _{1}^{1}\mathrm{H} \rightarrow _{2}^{3}\mathrm{He}$$

Which of the following is a valid reason as to why hydrogen fusion is not currently possible on Earth?

A Hydrogen fusion produces dangerous radioactive waste

B Hydrogen nuclei require very high temperatures to fuse together

C Hydrogen is a rare element that would be difficult to get large amounts of

D Hydrogen fusion does not produce enough energy to be commercially viable

ANSWER: B

- Hydrogen nuclei have **positive charges**
- So two hydrogen nuclei would have a **repulsive force** between them
- High temperatures are required to give the nuclei enough energy to overcome the repulsive force
- The answer is **not A** because the product of the hydrogen fusion shown in the reaction is helium
 - Helium is an inert gas
- The answer is **not C** because hydrogen is a very abundant element
 - It is the most common element in the universe
- The answer is **not D** because hydrogen fusion would produce a huge amount of energy

Your notes

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Stars

Your notes

Star Formation

1. Nebula

- All stars form from a giant interstellar cloud of **hydrogen gas** and **dust** called a **nebula**

2. Protostar

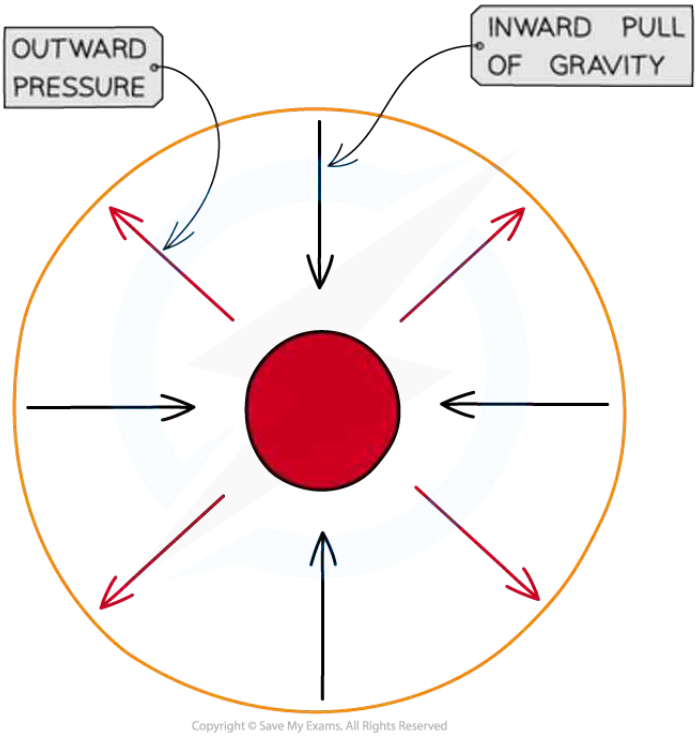
- The force of **gravity** within a nebula pulls the particles **closer together** until a hot ball of gas forms, this is known as a **protostar**
- As the particles are pulled closer together the **density** of the protostar will **increase**
 - This will result in **more frequent collisions** between the particles which causes the **temperature** to **increase**

3. Main Sequence Star

- Once the protostar becomes hot enough, nuclear fusion reactions occur within its core
 - The **hydrogen** nuclei will fuse to form **helium** nuclei
 - Every fusion reaction releases **heat** (and light) energy which keeps the core hot
- Once a star initiates fusion, it is known as a **main-sequence star**
- During the main sequence, the star is in **equilibrium** and said to be **stable**
 - The **inward force** due to **gravity** is **equal** to the **outward pressure force** from the fusion reactions

Equilibrium in a Star

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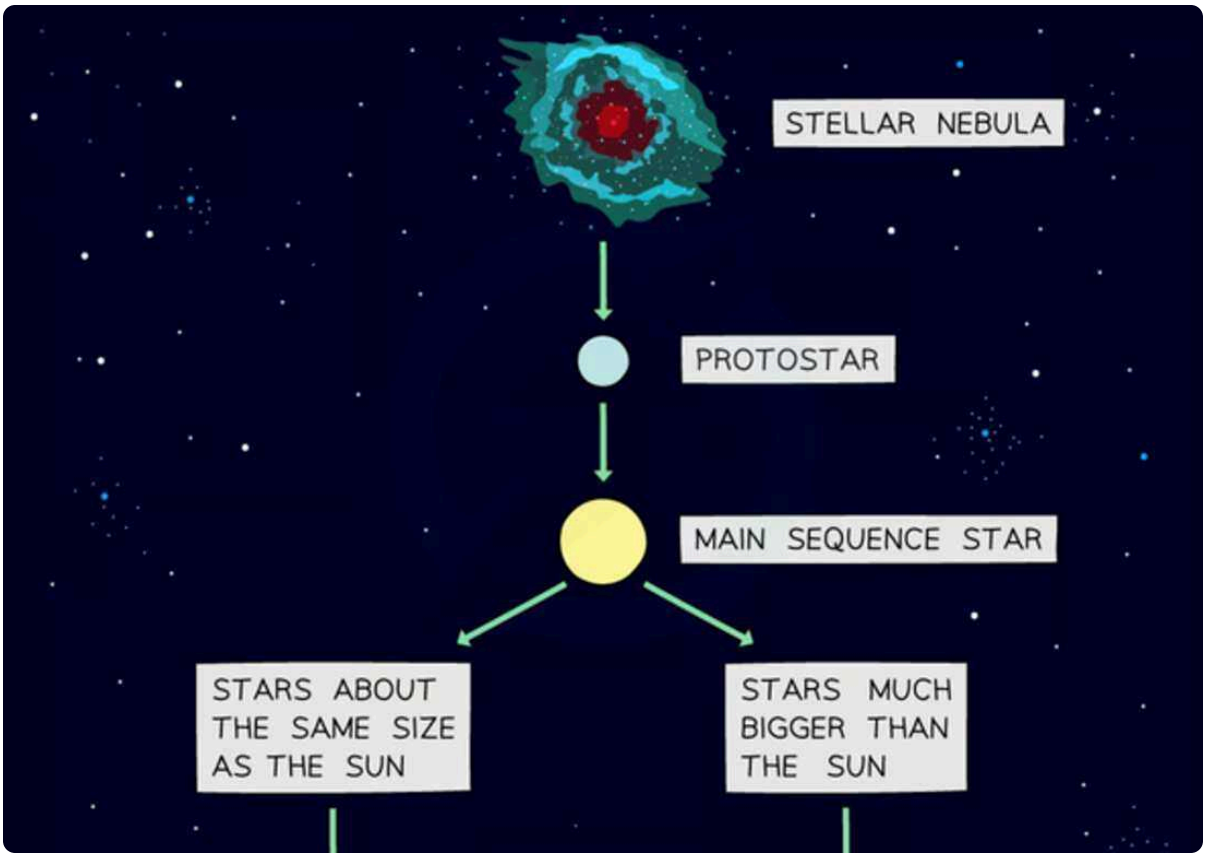
The outwards and inwards forces within a star are in equilibrium. The centre red circle represents the star's core and the orange circle represents the star's outer layers

- Once a protostar is formed, its life cycle will depend on its **mass**
- The different life cycles are shown below

Summary of the Life Cycles of Stars

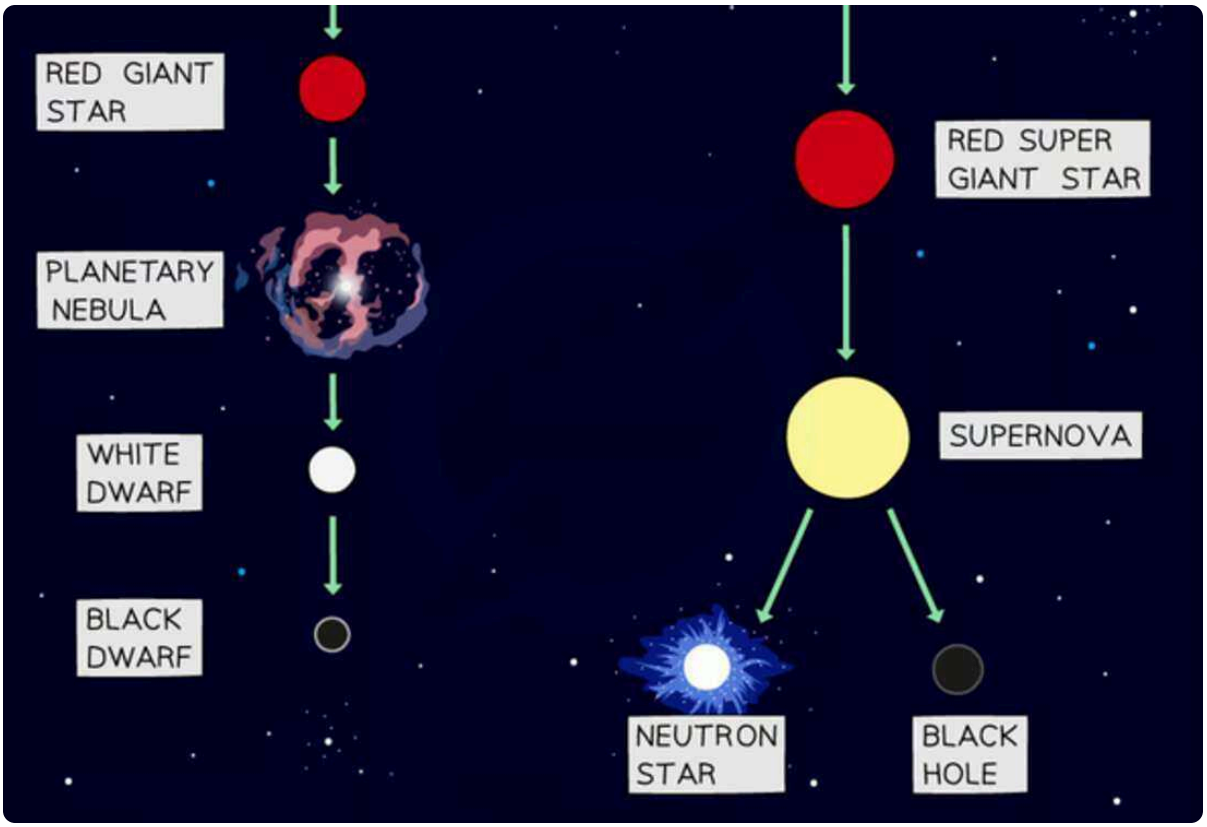
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Your notes

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Flow diagram showing the life cycle of a star which is the same size as the Sun (solar mass) and the lifecycle of a star which is much more massive than the Sun

Your notes

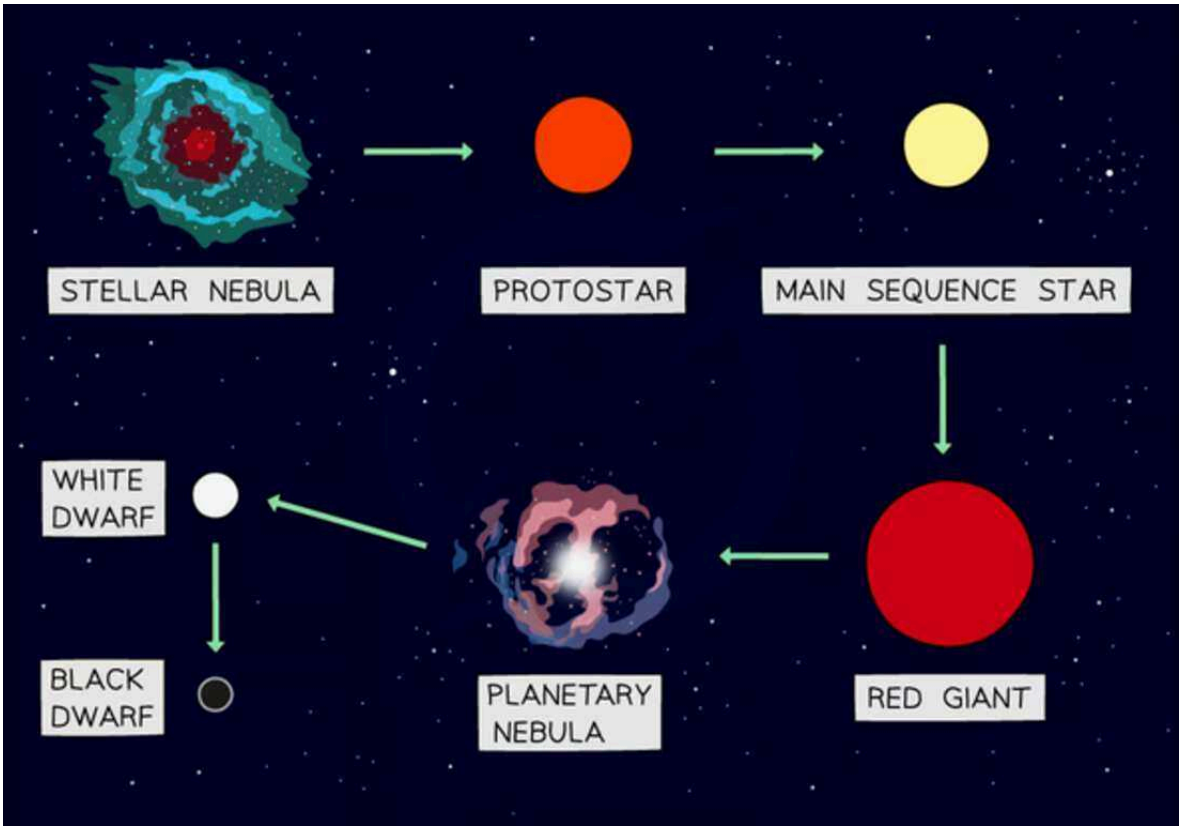
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Life Cycle of Low Mass Stars

Your notes

- A **low-mass** star will go through the following stages

Life Cycle of a Low-Mass Star



A low-mass star will complete its lifecycle as a red giant, a planetary nebula and eventually a white dwarf

4. Red Giant

- After several billion years the hydrogen causing the fusion reactions in the star will begin to run out
- Once this happens, the fusion reactions in the core will start to **die down**
- This causes the core to **shrink** and **heat up**
 - The core will shrink because the inward force due to gravity will become **greater** than the outward force due to the pressure of the expanding gases as the fusion dies down
- A new series of reactions will then occur around the core, for example, **helium** nuclei will undergo **fusion** to form **beryllium**
- These reactions will cause the outer part of the star to **expand**

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- A low-mass star that is up to 8 times the mass of **the Sun** or smaller will become a **red giant**
 - It is red because the **outer surface** starts to **cool**

5. Planetary Nebula

- Once this second stage of fusion reactions have finished, the star will become **unstable** and eject the outer layer of dust and gas
 - The layer of dust and gas which is ejected is called a **planetary nebula**

6. White Dwarf

- The core which is left behind will **collapse completely**, due to the pull of **gravity**, and the star will become a **white dwarf**
- The white dwarf will be **cooling** down and as a result, the amount of **energy** it emits will **decrease**

7. Black Dwarf

- Once the star has lost a significant amount of energy it becomes a **black dwarf**
- It will continue to cool until it eventually **disappears** from sight


Your notes

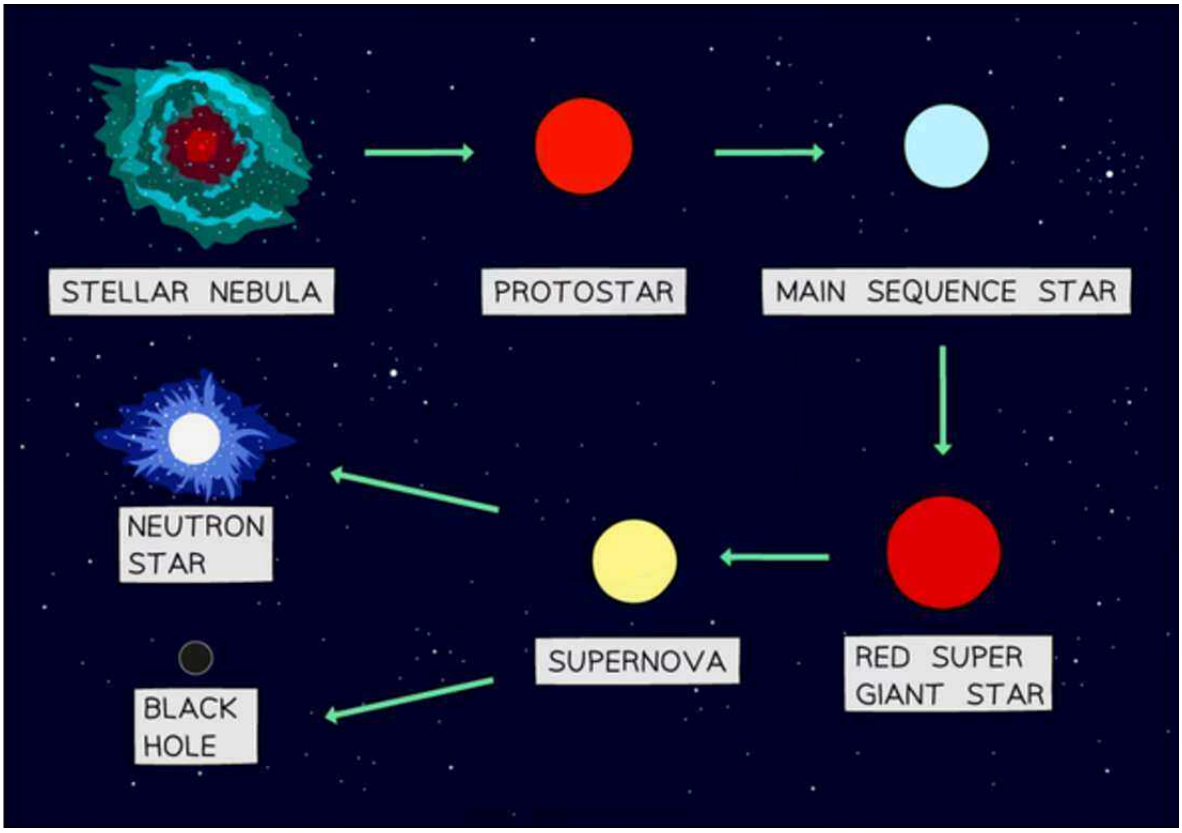
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Life Cycle of High Mass Stars

Your notes

- A **high-mass** star will go through the following stages

Life Cycle of a High-Mass Star



A high-mass star will complete its lifecycle as a red supergiant, a supernova and then either a neutron star, or a black hole

4. Red Supergiant

- After several **million** years, the hydrogen causing the fusion reactions in the star will begin to run out
 - A high-mass star (one **more** than 8 times the mass of the Sun) will become a **red supergiant**
- Similar to a low-mass star, the fusion reactions in the core will start to **die down**
- The core will go through a series of periods of **shrinking** and **heating up**
 - As a result, the outer parts of the star will **expand** and **contract**
- This time, fusion reactions will form elements all the way up to **iron**
- Fusion reactions cannot continue once iron is formed

5. Supernova

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- Once the fusion reactions inside the red supergiant cannot continue, the core of the star will **collapse suddenly** and cause a **gigantic explosion**
 - This is called a **supernova**
- At the centre of this explosion a **dense body**, called a **neutron star** will form
- The **outer remnants** of the star will be **ejected** into space during the supernova explosion, forming **new clouds** of dust and gas (**nebula**)
 - The nebula from a supernova may form **new stars** with **orbiting planets**


Your notes

6. Neutron Star (or Black Hole)

- In the case of the **biggest stars**, the neutron star that forms at the centre will continue to **collapse** under the force of **gravity** until it forms a **black hole**
 - A black hole is an **extremely dense** point in space that not even **light** can escape from

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The Universe


Your notes

Astronomical Distances

- **Astronomical distances**, such as the distances between stars and galaxies, are so **large** that physicists use a special unit to measure them called the **light-year**
- One light-year is defined as:

 The distance travelled by light through (the vacuum of) space in one year

- The speed of light is the **universal speed limit**, nothing can travel faster than the speed of light
- But over astronomical distances, light actually travels pretty slowly
- The **diameter of the Milky Way** is approximately **100 000 light-years**
 - This means that light would take 100 000 years to travel across it
- One light year is equal to 9.5×10^{12} km, or **9.5×10^{15} m**

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Redshift

Your notes

- Usually, when an object emits waves, the wavefronts spread out **symmetrically**
- If the wave source moves, the waves can become squashed together or stretched out

The Doppler Effect

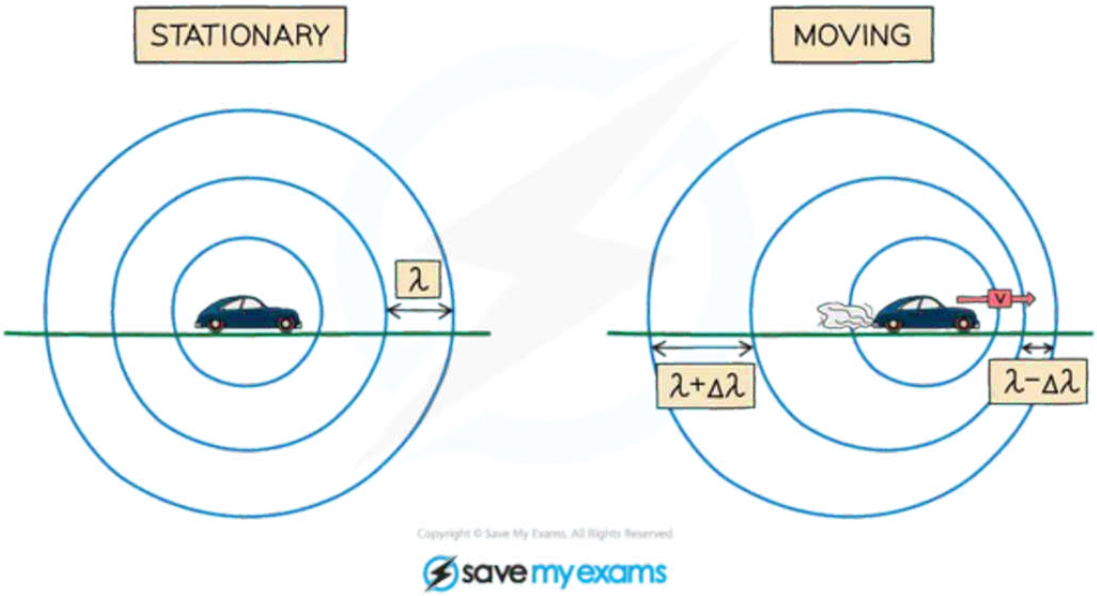


Diagram showing the wavefronts produced from a stationary object and a moving object

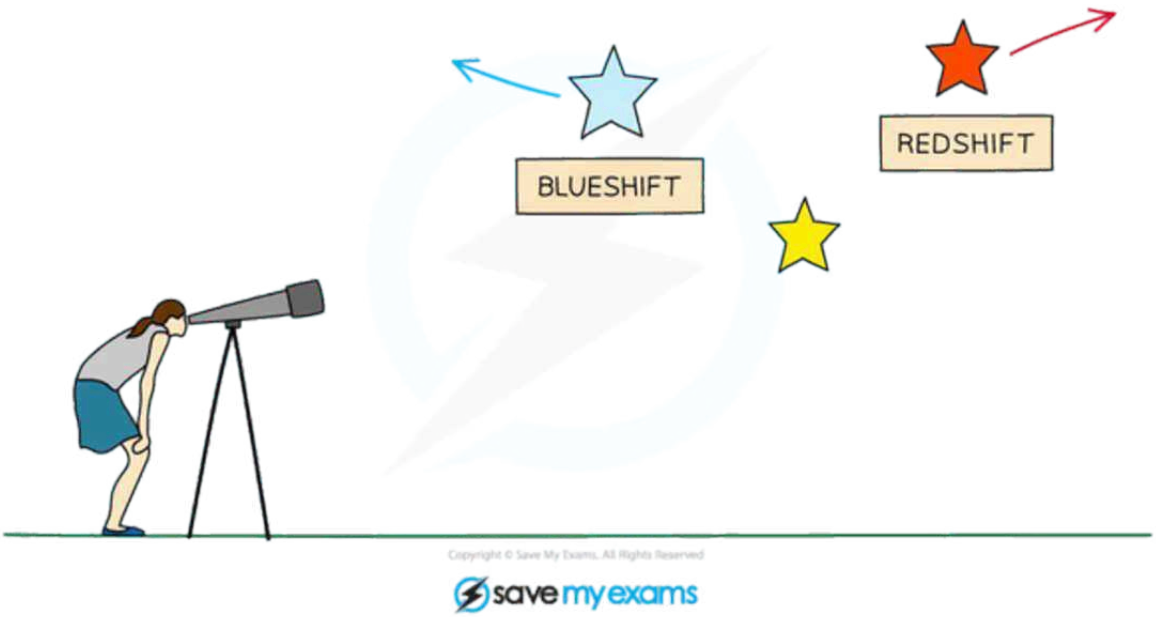
- A moving object will cause the **wavelength**, λ, (and frequency) of the waves to change:
 - The **wavelength** of the waves **in front** of the source **decreases** and the **frequency increases**
 - The wavelength **behind** the source **increases** and the **frequency decreases**
 - This effect is known as the **Doppler** effect
- The Doppler effect also affects **light**
 - If an object moves **away** from an observer the **wavelength of light increases**
 - This is known as **redshift** as the light moves towards the red end of the spectrum
- Redshift is defined as:

 An increase in the observed wavelength of electromagnet radiation emitted from receding stars and galaxies

Redshift & Blueshift

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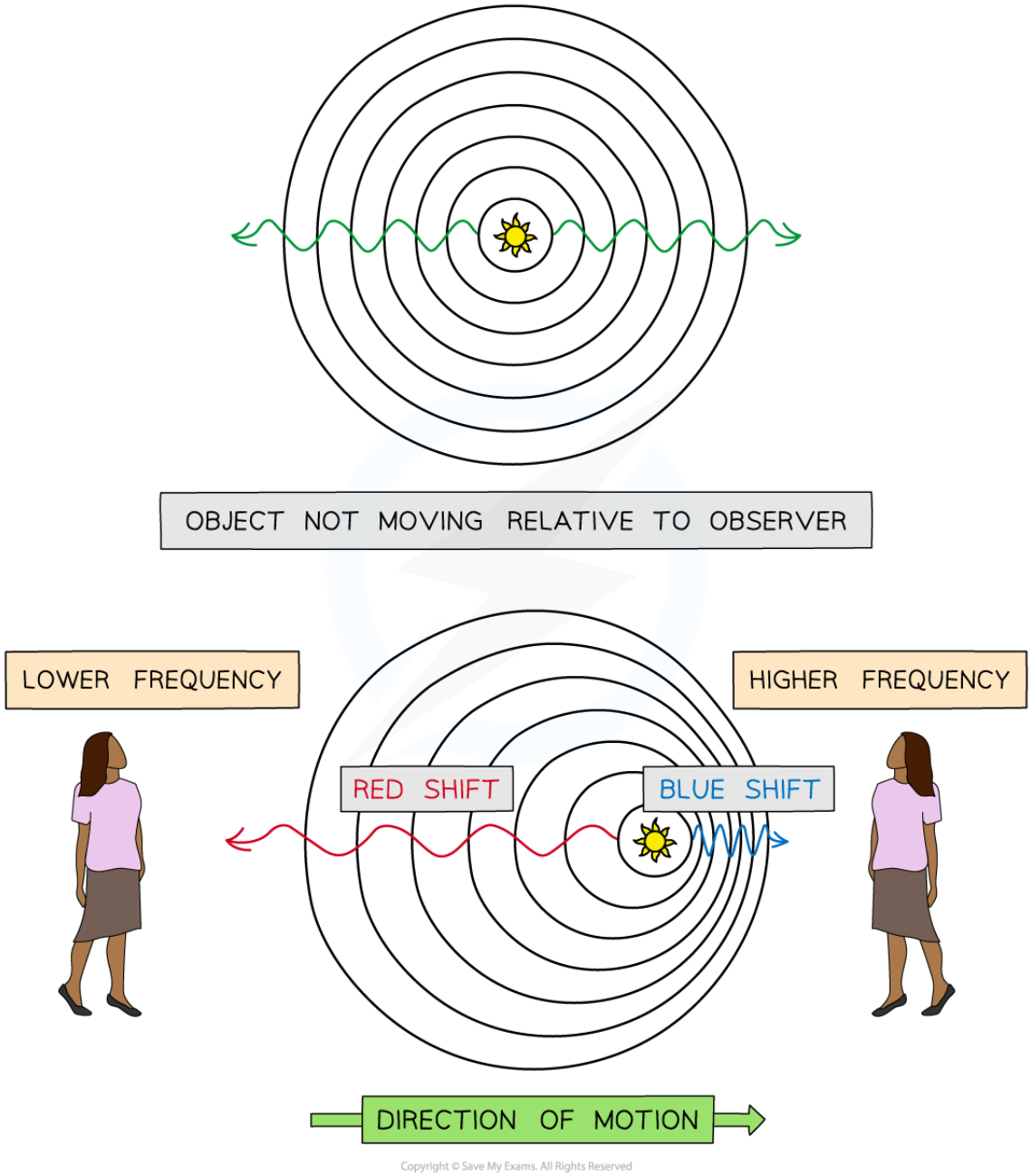
Your notes



Light from a star that is moving towards an observer will be blueshifted and light from a star moving away from an observer will be redshifted

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Your notes



The observer behind the source observes redshift

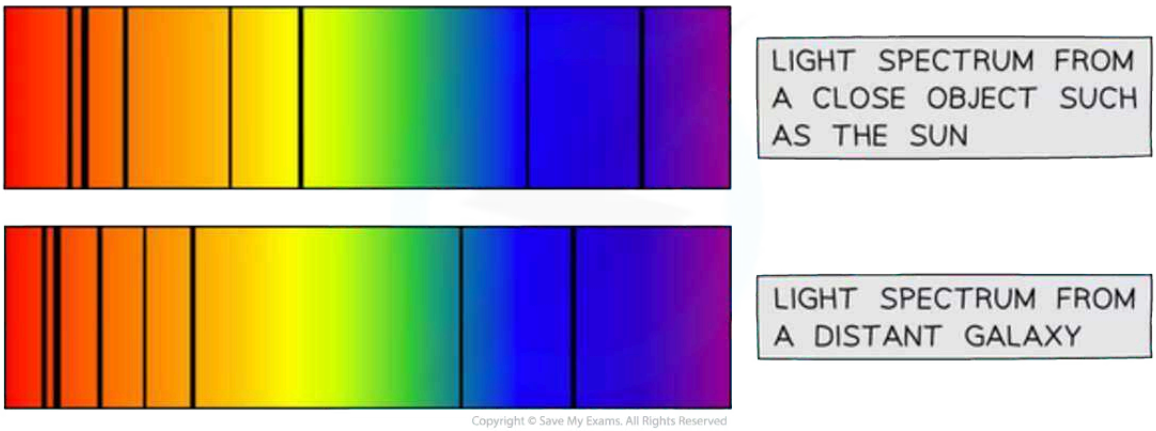
- The Milky Way is just one of **billions of galaxies** that make up the **Universe**
- Light emitted from **distant galaxies** appears **redshifted** when compared with light emitted on Earth

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- The diagram below shows the **light** coming to us from a **close object**, such as the Sun, and the light coming to us from a **distant galaxy**

Your notes

Comparison of Light Spectra



Comparing the light spectrum produced by the Sun and a distant galaxy

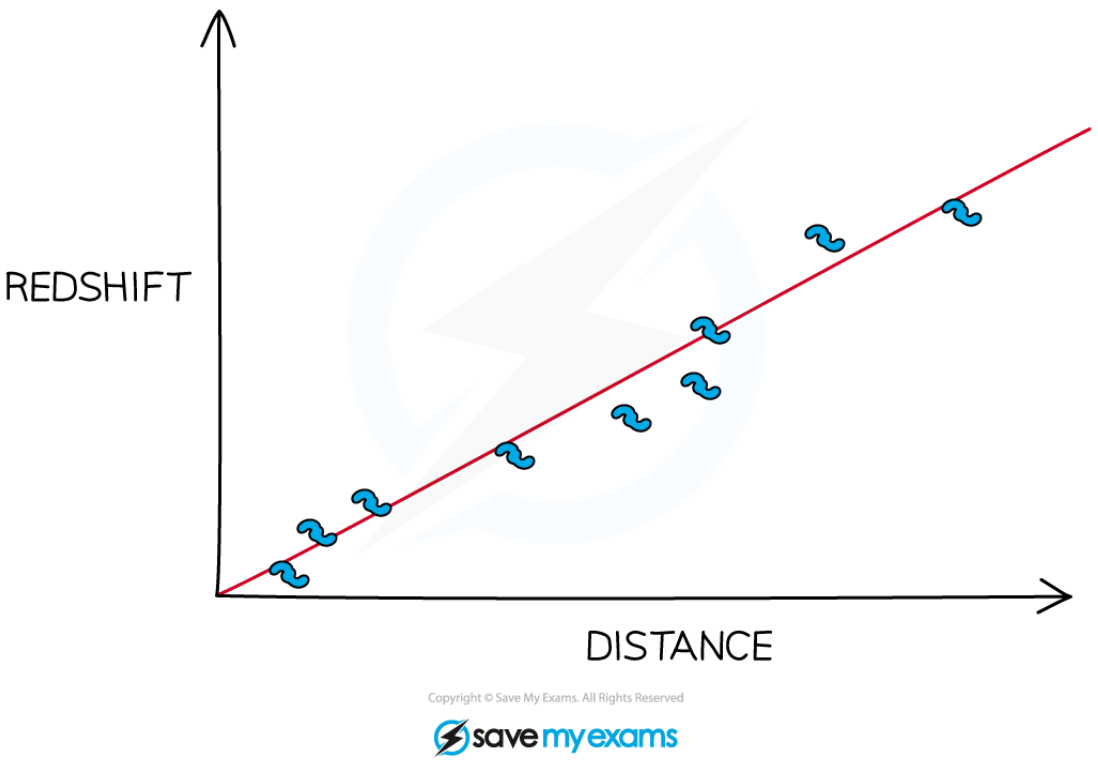
- The diagram also shows that the light coming to us from **distant galaxies** is **redshifted**
 - The lines on the spectrum are shifted towards the **red** end

- This indicates that the galaxies are moving **away** from us
- If the galaxies are moving away from us it means that the **universe is expanding**
- The observation of redshift from distant galaxies supports the **Big Bang theory**
- Another observation from looking at the light spectrums produced from distant galaxies is that the **greater** the **distance** to the galaxy, the **greater** the **redshift**
 - This means that the **further away** a galaxy is, the **faster** it is moving away from us

Redshift & Distance from Earth

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Your notes



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Graph showing the greater the distance to a galaxy, the greater the redshift

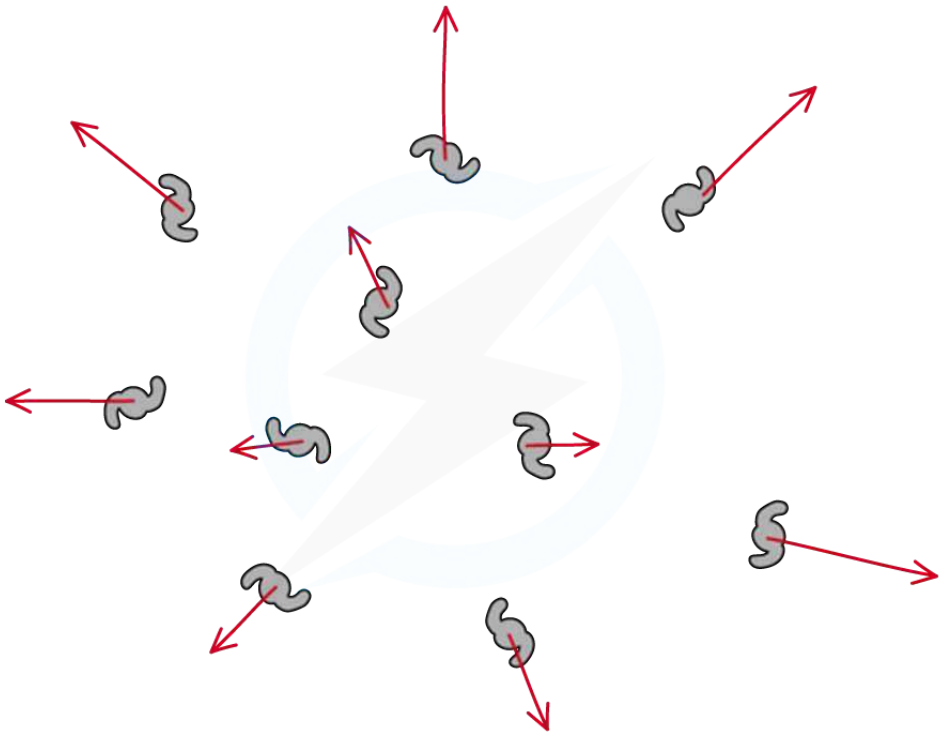
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The Big Bang

Your notes

- Around **14 billion years ago,** the Universe began from a **very small region** that was **extremely hot** and **dense**
- Then there was a **giant explosion**, which is known as the **Big Bang**
- This caused the universe to **expand** from a single point, cooling as it does so, to form the universe today
- Each point **expands away** from the others
 - This is seen from galaxies moving away from each other, and the further away they are the faster they move
- **Redshift** in the light from distant galaxies is evidence that the Universe is expanding and supports the Big Bang Theory
 - As a result of the initial explosion, the Universe **continues to expand**

Expansion of the Universe



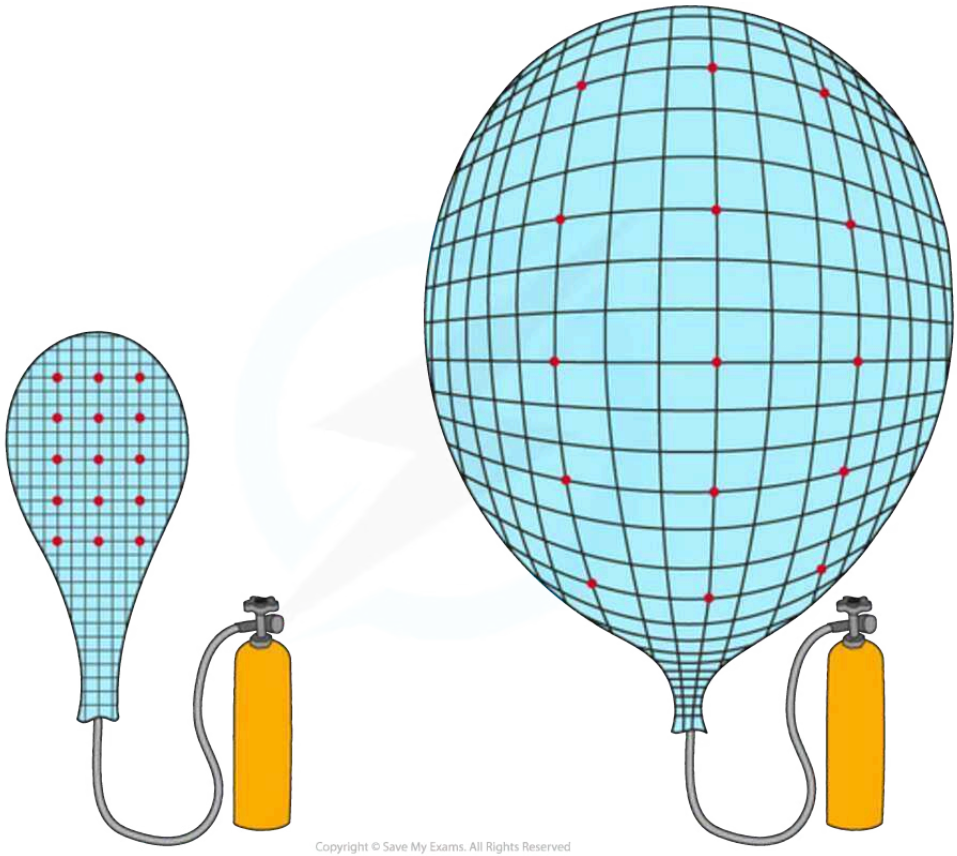
All galaxies are moving away from each other, indicating that the universe is expanding

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Your notes

- An analogy of this is points drawn on a balloon where the balloon represents space and the points as galaxies
 - When the balloon is deflated, all the points are close together and an equal distance apart
 - As the balloon expands, all the points become further apart **by the same amount**
 - This is because the **space itself** has expanded between the galaxies

Analogy for the Expanding Universe



A balloon inflating is similar to the stretching of the space between galaxies

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